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# PROCEEDINGS

OF THE

# AMERICAN SOCIETY OF AGRONOMY

VOLUME 3

1911

PUBLISHED BY THE SOCIETY
1912

# OFFICERS.

### 1907–1908.

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# PREFACE.

The American Society of Agronomy was organized on December 31, 1907. Six scientific meetings have been held, namely, Chicago, December 31, 1907–January 1, 1908; Ithaca, July 9–11, 1908; Washington, November 17–18, 1908; Omaha, December 7–8, 1909; Washington, November 14–15, 1910, and Columbus, November 13–14, 1911. The last four were annual meetings. At the Omaha meeting the printing of the Proceedings was authorized.

Volume 1 of the Proceedings covered the years 1907–1909, inclusive. It contained thirty-nine of the sixty-nine papers presented at the first four meetings, seventeen having been otherwise published and thirteen withdrawn for various reasons. The index for volume 1 will be found in volume 2.

Volume 2 covers the year 1910. It includes fifteen of the twenty papers presented at the Washington meeting and also one paper subsequently submitted for publication.

The present volume, for the year 1911, contains fourteen papers of which nine were presented at the annual meeting at Columbus and the other five, by Messrs. Bouyoucos, Burgess, Coffey, Morgan and Wiancko, respectively, were later accepted for publication. The remaining seven papers presented at the annual meeting, by Messrs. Briggs and Shantz, Davis, Hays, Lyon, Montgomery and Wiancko, were withdrawn for various reasons.

Volume 3 contains a considerable increase over volume 2 in the number of pages and of illustrations also. The chief new feature is the inclusion of two doctorate theses, by Doctors Bouyoucos and Morgan.

In accordance with the statement made by the Secretary at Columbus, volume 3 is issued approximately six months earlier in the year than volume 2. The willing cooperation of the authors, which made possible this prompt appearance, is largely appreciated by the Committee on Publication. It is hoped that errors and omissions may prove few.

Many new members have been added since the last annual meeting. A little work on the part of each present member in obtaining others from among the many eligible men will make financially possible the founding of a journal of agronomy early in 1913. Let all work together for this end.

Respectfully submitted,
C. V. Piper, *Chairman.*
Carleton R. Ball,
T. Lyttleton Lyon,
*Committee on Publication.*

# BUSINESS SECTION.

## REPORT OF THE SECRETARY FOR 1911.

The year just closing has been a very busy one for your Secretary. The chief matters requiring attention have been the distribution and sale of Volume 1, determining the bona fide membership of the Society at the beginning of the year, the collection of papers for Volume 2, the editing and proofreading of the manuscript, the recent distribution of Volume 2 to members, and the making of necessary arrangements for the current meeting. These activities have necessitated the writing of 330 personal letters, in addition to the large number of circular letters sent out. In connection with these clerical duties it is a pleasure to acknowledge here the assistance received from Miss Mary E. Holland, without which the work could scarcely have been done.

It is very gratifying to be able to report at this fourth annual meeting that, from all standpoints, the Society is in a progressive and prosperous condition.

### 1. FUNDS COLLECTED BY THE SECRETARY.

At the third annual meeting it was voted that the Proceedings should be sent to no members in arrears for dues. There were many members in arrears, some for a period of two years. In order to prepare as quickly as possible a correct list of actual members for the mailing of Volume 1 and for inclusion in Volume 2, the Secretary, with the approval of the new Treasurer, undertook the collection of these arrearages. After considerable personal correspondence, dues in arrears, amounting to $140, were obtained and 22 names dropped from the rolls for non-payment. In addition to this amount, considerable sums were received as dues accompanying the applications of new members and from the sale of Volume 1.

There follows a classified list of these funds, all of which have been transmitted to the Treasurer, receipted for by him, and included in his forthcoming annual report.

Classified Funds Collected and Transmitted by the Secretary, November, 1910, to July 20, 1911, Inclusive.

*Receipts.*

| | | |
|---|---|---|
| Arrears for 1909 from 20 members | $ 40.00 | |
| Arrears for 1910 from 50 members | 100.00 | |
| Dues for 1910 from 22 new members | 44.00 | |
| Dues for 1911 from 14 new members | 28.00 | |
| Dues for 1911 from 22 old members | 44.00 | |
| Reimbursement for authors' reprints | 31.40 | |
| Sale of 30 copies Volume 1 of Proceedings | 60.00 | $347.40 |

*Disbursements.*

| | | |
|---|---|---|
| Dec. 9, 1910, to L. Carrier, Treasurer | $100.00 | |
| Jan. 21, 1911, to L. Carrier, Treasurer | 100.00 | |
| Feb. 11, 1911, to L. Carrier, Treasurer | 100.00 | |
| Apr. 7, 1911, to L. Carrier, Treasurer | 23.40 | |
| July 17, 1911, to L. Carrier, Treasurer | 24.00 | $347.40 |

## 2. MEETINGS.

The Society has held five meetings, one for organization, three annual, and one a summer meeting. Eighty-nine papers have been presented, or an average of 18 papers for each meeting. Fifty-four of these have been published in Volumes 1 and 2 of the PROCEEDINGS.

The organization meeting was held in Chicago and the annual meetings have been held in Washington, Omaha and, again, at Washington. The present gathering is the fourth annual meeting. The single summer meeting was held at Ithaca, N. Y., in 1908, in connection with the Graduate School of Agriculture.

The question of holding summer meetings each year, or at least once in two years, is one deserving of serious consideration. With our members scattered throughout the length and breadth of North America, it is impossible for a very large proportion of them to attend any one meeting. By multiplying the number of meetings and distributing them geographically, a larger number of members can obtain the inspiration and enjoy the fellowship which make so largely for growth and improvement in any organization. It would seem that the biennial sessions of the Graduate School of Agriculture furnish a suitable medium for a summer meeting every second year. This school occurs in the even numbered years, in which the affiliating agricultural organizations are accustomed to hold their annual meetings regularly in Washington, D. C. In the alternating years a summer meeting might well be held at some point in the west in connection with one or another of the various agricultural gatherings, such as the Dry-Farming Congress, Irrigation Congress, or similar bodies whose meetings a large number of our agronomists are accustomed to attend.

## 3. MEMBERSHIP OF THE SOCIETY.

### COMPARATIVE STATISTICS.

The statistics of membership appearing on pages 17–23, inclusive, of Volume 2 of the PROCEEDINGS, show that at the end of 1910 the Society had a bona fide paid membership of 167 workers in agronomy. Two members have since resigned. During 1911, 46 new members already have been added, making a total of 211 to date. The accessions for 1909 were 26; for 1910, they were 46. While those for 1911 already equal those for 1910, it is probable that they will much exceed them at the end of the calendar year.[1] Membership taken for the year 1911 entitles the holder to the PROCEEDINGS resulting from the meeting now in progress. For this reason a number who join within the next few weeks will elect to take membership for 1911, in order that they may thereby obtain the forthcoming volume without further effort.

---

[1] The accessions for 1911 have since been increased to 71, making a present total of 236 members.—SECRETARY.

There are at least three hundred more men in North America eligible to active membership in our Society. The number is increasing every year. It should be possible to actively interest fifty or seventy-five percent of this number in the work of our Society to the extent of their taking membership and working with us for the advancement of American agronomy. The changing of the constitution so as to permit the ready formation of local sections should prove a strong factor in adding both associate and active members, as well as the local members provided for by the proposed amendment. Let us set before us the goal of 400 members by the next annual meeting in 1912, and then press forward toward that mark.

## New Members in 1911.

Bell, Henry G.
Benzin, Basil M.
Binford, E. E.
Boss, Andrew
Bower, H. J.
Bowman, Albert E.
Brown, P. E.
Buchanan, J.
Champlin, Manley
Churchill, O. O.
Clark, Chas. F.
Critz, Hugh
Davis, R. O. E.
Delwiche, E. J.
Etheridge, W. C.
Evans, C. M.
Fain, John R.
Fitz, L. A.
Fox, J. W.
Frear, D. W.
Goddard, L. H.
Grant, C. J.
Griggs, W. D.
Güell, Aurelio R.
Hallsted, A. L.
Hand, W. F.
Harris, A. L.
Hartley, C. P.
Hayes, Herbert K.
Holt, S. V.
Hopt, Erwin
Hutchinson, W. L.
Kinney, E. J.
Klein, Millard A.
Lathrop, E. C.
Laude, Hilmer H.
Leidigh, A. H.
Lill, J. G.
Lipman, C. B.
Livingston, G.
Lloyd, E. R.
Lloyd, W. A.
McDowell, J. C.
McKee, Clyde
McKee, Roland
McKnight, H. L.
McMillan, S. A.
Meyers, C. H.
Morse, Fred. W.
Napier, J. M.
Nichols, Mark L.
Packard, Walter E.
Quereau, F. C.
Reid, F. R.
Roberts, Geo.
Rothgeb, B. E.
Schafer, E. G.
Schutz, H. H.
Scofield, C. S.
Skinner, J. J.
Stanton, T. R.
Stewart, Robt.
Turlington, J. E.
Wheeler, Clark S.
Wheeler, H. C.
Widtsoe, John A.
Willier, J. G.
Winters, R. Y.
Woodard, John
Youngblood, Bonney
Zook, L. L.

## List of Present Members, with Addresses.

Adams, G. E., Experiment Station, Kingston, R. I.
Aicher, L. C., Experiment Substation, Aberdeen, Idaho.
Allen, Edward R., 112 Stewart Ave., Ithaca, N. Y.
Alway, F. J., Experiment Station, Lincoln, Nebr.
Atkinson, Alfred, Experiment Station, Bozeman, Mont.
Babcock, F. R., Experiment Farm, Williston, N. Dak.
Ball, Carleton R., Bu. Plant Indus., U. S. Dept. of Agr., Washington, D. C.

Ball, Elmer D., Experiment Station, Logan, Utah.
Bartlett, Harley Harris, Bu. Plant Indus., Dept. of Agr., Washington, D. C.
Bell, Henry G., Nat'l Fertilizer Assoc., 919 Postal Tel. Bldg., Chicago, Ill.
Bell, James M., University of North Carolina, Chapel Hill, N. C.
Bennett, Hugh H., Bu. Soils, Dept. of Agr., Washington, D. C.
Benzin, Basil M., Imp. Dept. of Agriculture, St. Petersburg, Russia.
Binford, E. E., Agricultural College, College Station, Tex.
Bizzell, James A., Cornell University, Ithaca, N. Y.
Bolley, H. L., Experiment Station, Agricultural College, N. Dak.
Bonns, W. W., Highmoor Farm, Monmouth, Maine.
Boss, Andrew, Experiment Station, University Farm, St. Paul, Minn.
Bouyoucos, G. J., Experiment Station, East Lansing, Mich.
Bower, H. J., 181 W. 8th Ave., Columbus, Ohio.
Bowman, Albert E., Experiment Station, Logan, Utah.
Bracken, John, Saskatoon, Saskatchewan, Canada.
Briggs, Lyman J., Bu. Plant Indus., U. S. Dept. Agr., Washington, D. C.
Brodie, D. A., Bu. Plant Indus., U. S. Dept. of Agr., Washington, D. C.
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Brown, P. E., Dept. Agronomy, Iowa State College, Ames, Iowa.
Buchanan, J., Dept. Agronomy, Iowa State College, Ames, Ia.
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Bull, C. P., Experiment Station, University Farm, St. Paul, Minn.
Burgess, James L., State Dept. of Agriculture, Raleigh, N. C.
Butler, Ormond R., University of Wisconsin, Madison, Wis.
Call, L. E., Experiment Station, Manhattan, Kans.
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Churchill, O. O., Agricultural College, Stillwater, Okla.
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Crabb, Geo. A., Cornell University, Ithaca, N. Y.
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Eastman, J. F., State School of Agriculture, Morrisville, N. Y.
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Griggs, W. D., Experiment Farm, Dalhart, Texas.
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Hallsted, A. L., Branch Experiment Station, Hays, Kans.
Hand, W. F., Dept. Chemistry, Agricultural College, Miss.
Harris, A. L., Agricultural College, College Station, Texas.
Harris, F. S., Experiment Station, Logan, Utah.
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Hays, W. M., U. S. Dept. of Agr., Washington, D. C.
Holt, S. V., Experiment Station, Urbana, Ill.
Hopkins, Cyril G., University of Illinois, Urbana, Ill.
Hopt, Erwin, University Farm, Lincoln, Nebr.
Hsieh, E. L., Cornell University, Ithaca, N. Y.
Humbert, Eugene P., Experiment Station, Agricultural College, N. M.
Hunt, Thomas F., Experiment Station, State College, Pa.

Hurd, Wm. D., Agricultural College, Amherst, Mass.
Hutchinson, W. L., Agricultural College, Miss.
Hutchison, Geo. S., Care The Albert Dickinson Co., Chicago, Ill.
Hyslop, R. E., Moscow, Idaho.
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Jenkins, J. Mitchell, Rice Experiment Station, Crowley, La.
Johnson, Edw. C., Bu. Plant Indus., U. S. Dept. of Agr., Washington, D. C.
Keyser, Alvin, Experiment Station, Fort Collins, Colo.
Kidder, A. F., Louisiana Agricultural College, Baton Rouge, La.
Kiesselbach, T. A., Experiment Station, Lincoln, Nebr.
Kilgore, B. W., State Dept. of Agriculture, Raleigh, N. C.
Kinney, E. J., Experiment Station, Lexington, Ky.
Klein, Millard A., 317 Eddy St., Ithaca, N. Y.
Klinck, L. S., Macdonald College, Macdonald College, P. Q., Canada.
Krauss, F. G., Experiment Station, Honolulu, H. I.
Lathrop, E. C., Bu. Soils, U. S. Dept. of Agr., Washington, D. C.
Laude, Hilmer H., Dept. Agronomy, Agricultural College, Manhattan, Kans.
LeClerc, J. A., Bu. Chemistry, U. S. Dept. of Agr., Washington, D. C.
Leidigh, A. H., Experiment Station, Manhattan, Kans.
Lill, J. G., Dept. Agronomy, Agricultural College, Manhattan, Kans.
Lipman, C. B., Experiment Station, Berkeley, Calif.
Lipman, I. B., 414 Cascadilla Bldg., Ithaca, N. Y.
Lipman, Jacob G., Experiment Station, New Brunswick, N. J.
Livingston, G., Townshend Hall, Ohio State Univ., Columbus, Ohio.
Lloyd, E. R., Agricultuarl College, Miss.
Lloyd, W. A., Experiment Station, Wooster, Ohio.
Loughridge, R. H., University of California, Berkeley, Calif.
Lumbrick, A., College of Agriculture, Urbana, Ill.
Lynde, C. J., Macdonald College, Macdonald College, P. Q., Canada.
Lyon, T. Lyttleton, Cornell University, Ithaca, N. Y.
McCall, Arthur G., Ohio State University, Columbus, Ohio.
McDowell, J. C., Waukesha, Wis.
McKee, Clyde, Akron Substation, Akron, Colo.
McKee, Roland, Bu. Plant Indus., U. S. Dept. of Agr., Washington, D. C.
McKnight, H. L., Experiment Station, College Station, Texas.
McMillan, S. A., Agricultural College, College Station, Texas.
Mackie, W. W., Esperanza, Sonora, Mexico.
Marbut, C. F., 3555 11th St., N. W., Washington, D. C.
Merrill, L. A., Vermont Bldg., Salt Lake City, Utah.
Meyers, C. H., College of Agriculture, Ithaca, N. Y.
Miller, M. F., Experiment Station, Columbia, Mo.
Minns, Edward R., Cornell University, Ithaca, N. Y.
Montgomery, E. G., College of Agriculture, Ithaca, N. Y.
Mooers, Chas. A., Experiment Station, Knoxville, Tenn.
Moore, R. A., University of Wisconsin, Madison, Wis.
Moorhouse, L. A., 203 Majestic Bldg., Denver, Colo.
Morgan, J. O., Experiment Station, College Station, Miss.
Morse, Fred. W., Experiment Station, Amherst, Mass.
Morse, W. J., 121 V St., N. W., Washington, D. C.

Mosher, M. L., Iowa State College, Ames, Iowa.
Mosier, J. G., Experiment Station, Urbana, Ill.
Musback, Fred L., University of Wisconsin, Madison, Wis.
Napier, J. M., Clemson Agricultural College, Clemson College, S. C.
Nash, C. W., Experiment Station, Manhattan, Kans.
Nelson, Martin, Experiment Station, Fayetteville, Ark.
Nichols, Mark L., 67 W. 10th Ave., Columbus, Ohio.
Oakley, R. A., Bu. Plant Indus., U. S. Dept. of Agr., Washington, D. C.
Orton, W. A., Bu. Plant Indus., U. S. Dept. of Agr., Washington, D C.
Packard, Walter E., El Centro, Calif.
Patten, Harrison E., Bu. Chemistry, U. S. Dept. of Agr., Washington, D. C.
Patterson, H. J., Experiment Station, College Park, Md.
Pettit, J. H., College of Agriculture, Urbana, Ill.
Piper, C. V., Bu. Plant Indus., U. S. Dept. of Agr., Washington, D. C.
Potter, Harry B., Care of Farm and Fireside, Springfield, Ohio.
Pugsley, C. W., Experiment Station, Lincoln, Nebr.
Quereau, F. C., Rice Experiment Farm, Crowley, La.
Reid, F. R., Bu. Soils, U. S. Dept. of Agr., Washington, D. C.
Roberts, Geo., Experiment Station, Lexington, Ky.
Roberts, H. F., Experiment Station, Manhattan, Kans.
Ross, John F., Experiment Farm, Amarillo, Texas.
Rothgeb, B. E., Bu. Plant Indus., U. S. Dept. of Agr., Washington, D. C.
Salmon, Cecil, Bellefourche Experiment Farm, Newell, S. Dak.
Schafer, E. G., Dept. Agronomy, Agricultural College, Manhattan, Kans.
Schmitz, Nickolas, Experiment Station, College Park, Md.
Schreiner, Oswald, Bu. Soils, U. S. Dept. of Agr., Washington, D. C.
Schutz, H. H., Southwestern Irrigation, Land and Power Co., Los Lunas, N. M.
Scofield, C. S., Bu. Plant Indus., U. S. Dept. of Agr., Washington, D. C.
Scudder, H. D., Experiment Station, Corvallis, Oregon.
Selvig, C. G., Northwest Experiment Station, Crookston, Minn.
Shantz, H. L., Bu. Plant Indus., U. S. Dept. of Agr., Washington, D. C.
Shaw, Chas. F., Experiment Station, State College, Pa.
Shepperd, J. H., Experiment Station, Agricultural College, N. Dak.
Shoesmith, V. M., Experiment Station, East Lansing, Mich.
Shutt, Frank T., Experimental Farm, Ottawa, Canada.
Sinha, Satyasaran, 28/1 Sukeas St., Calcutta, India.
Skinner, Joshua J., Bu. Soils, U. S. Dept. of Agr., Washington, D. C.
Slate, W. L., Jr., University of Maine, Orono, Me.
Smith, L. H., College of Agriculture, Urbana, Ill.
Snyder, Harry, 2020 Commonwealth Ave., St. Paul, Minn.
Spillman, W. J., Bu. Plant Indus., U. S. Dept. of Agr., Washington, D. C.
Spragg, F. A. Experiment Station, East Lansing, Mich.
Squires, J. H., Technical Div., Dupont Powder Co., Wilmington, Del.
Stanton, T. R., Hyattsville, Md.
Stevenson, W. H., Experiment Station, Ames, Iowa.
Stewart, Robt., Experiment Station, Logan, Utah.
Stoddart, Chas. W., State College, Pa.
Stone, J. L., Experiment Station, Ithaca, N. Y.
Summerby, R., Macdonald College, Macdonald College, P. Q., Canada.

Taliaferro, W. T. L., Agricultural College, College Park, Md.
Taylor, F. W., Experiment Station, Durham, N. H.
Ten Eyck, A. M., Branch Experiment Station, Hays, Kans.
Thatcher, R. W., Experiment Station, Pullman, Wash.
Thompson, M. J., University Farm, St. Paul, Minn.
Thorne, Chas. E., Experiment Station, Wooster, Ohio.
Tinsley, J. D., 902 So. Second St., Albuquerque, N. M.
Tracy, S. M., Biloxi, Miss.
Turlington, J. E., College of Agriculture, Ithaca, N. Y.
Umberger, H. J. C., Experiment Station, Manhattan, Kans.
Veitch, F. P., Bu. Chemistry, U. S. Dept. of Agr., Washington, D. C.
Vinall, Harry N., Bu. Plant Indus., U. S. Dept. of Agr., Washington, D. C.
Waldron, L. R., Experiment Substation, Dickinson, N. Dak.
Warren, G. F., Cornell Experiment Station, Ithaca, N. Y.
Westgate, J. M., Bu. Plant Indus., U. S. Dept. of Agr., Washington, D. C.
Wheeler, Clark S., 67 West 10th Ave., Columbus, Ohio.
Wheeler, H. C., 1018 W. Oregon St., Urbana, Ill.
Wheeler, H. J., Experiment Station, Kingston, R. I.
Whiting, Albert L., University of Illinois, Urbana, Ill.
Whitson, A. R., Experiment Station, Madison, Wis.
Wiancko, A. T., Experiment Station, Lafayette, Ind.
Widtsoe, John A., Agricultural College, Logan, Utah.
Williams, C. G., Experiment Station, Wooster, Ohio.
Willier, J. G., 1129 Euclid St., N. W., Washington, D. C.
Winters, R. Y., College of Agriculture, Ithaca, N. Y.
Wood, M. W., Boise, Idaho.
Woodard, John, Agricultural Building, Urbana, Ill.
Woods, A. F., Experiment Station, University Farm, St. Paul, Minn.
Woods, Chas. D., Experiment Station, Orono, Maine.
Worthen, E. L., State Board of Agriculture, Raleigh, N. C.
Youngblood, Bonney, Experiment Station, College Station, Texas.
Zavitz, C. A., Ontario Agricultural College, Guelph, Ontario.
Zook, L. L., Corn Investigations, 928 F St., N. W., Washington, D. C.

## 4. PROCEEDINGS.

On November 3 and 4 your Secretary distributed the second volume of the Proceedings to the 167 paid members for 1910. Like Volume 1, the second volume has been issued in an edition of 500 copies, or, more accurately, of 516 copies. Of these, 167 have been used to supply the paid membership of 1910, as previously noted. Three hundred and forty-nine remain as a reserve stock from which to supply libraries, new members and others. In like manner, of the 500 copies printed of Volume 1, the paid membership required 129 copies, while 24 have been sold to new members, 6 to libraries, and 1 to a non-member, making a total of 160. Three hundred and forty therefore remain for future disposition.

### New Features.

There are three new features in Volume 2 which it is believed mark an improvement over its predecessor. The first is the use of the name of the author and title of his paper as a running head at the top of each right-hand page. This facilitates ready reference to the text beneath. The same plan is followed in the Business Section as well. The second feature is the index. None was provided for Volume 1, but separate indices for both Volumes 1 and 2 are included in the present volume. The third new feature is the inclusion of portraits and brief biographical and bibliographical sketches of our first President, Professor M. A. Carleton, and our first Secretary, Dr. T. Lyttleton Lyon. It is hoped that all these innovations may commend themselves to the membership.

### COST OF VOLUME 2.

The cost of this issue is less than for Volume 1, because it contains fewer pages. Page for page, however, the cost is greater, because of the more numerous illustrations, especially half-tones, and also the slightly higher estimates received. Where Volume 1 contained three small half-tone text figures, Volume 2 contains six full-page plates, besides 22 line engravings, some of them full-page also. The comparative cost per copy of the two volumes is shown in the following table:

*Cost Per Copy, in Edition of Five Hundred Copies.*

| | Vol. 1. | Vol. 2. |
|---|---|---|
| Printing and binding | $1.039 | $ .73 |
| Illustrations, making and insertion | .015 | .125 |
| Wrapping and mailing, labor and material | .02 | .025 |
| Postage | .11 | .09 |
| Miscellaneous | .016 | .01 |
| Total | $1.20 | $0.98 |

### CONTENTS OF THE VOLUME.

The second volume contains 154 pages of printed matter of which pages 1 to 31 are devoted to the Business Section, pages 33 to 147 to the Scientific Section, and pages 148 to 154 to the indices.

#### *Business Section.*

In the Business Section the items most important to the membership at large are the list of members with addresses and the full report of the Committee on Affiliation.

It is greatly to be regretted that in spite of all efforts a few errors have been discovered in the address list. It is probable also that the publication of this list will awaken many members to the fact that they have changed their addresses without notifying the Secretary. Through the notes published in the Experiment Station Record and in Science, as well as through other sources, the Secretary endeavors to keep track of changing addresses. It cannot be done accurately in this way, however, and members are urged to notify the Secretary promptly of any changes in their addresses.

Special attention is directed to the printed report of the Affiliation Committee. The meeting of the Joint Committee on Affiliation was held last November on the evening following the adjournment of our meeting. The representatives of this Society could not report, therefore, at the business session of that meeting. Under the circumstances your Secretary thought it desirable to print the report in full in advance of the presentation, in order that members might be informed of the progress and present status of the affiliation movement. That the spirit of coöperation and affiliation is operating before official affiliation is obtained, is clearly shown by the three joint sessions scheduled for this meeting. Acknowledgment is here made of the courtesy of Dr. E. W. Allen, Secretary of the Society for the Promotion of Agricultural Science, in assisting to arrange these joint meetings.

### *Scientific Section.*

The Scientific Section contains 15 of the 20 papers submitted at the annual meeting last November (1910), and, in addition, one paper received subsequent to that meeting and approved by the Committee on Publication. The paper so approved is by H. O. Buckman, a graduate student in the Department of Agronomy at Cornell University, and entitled "Moisture and Nitrate Relations in Dry Land Agriculture," presented as a contribution from the Agronomy Department of the Montana Agricultural College. This paper was accepted and published without authority from the Society. Your Secretary would recommend that authority be given to the Committee on Publication to accept hereafter for publication any suitable papers offered even though not previously presented before this Society.

### Publication of a Journal.

The time seems ripe for this Society to consider the publication of a journal appearing at least bi-monthly, and possibly in monthly issues. It is patent to every member that there is an increasing need for such a medium of agronomic expression in this country. It is equally evident that upon no other organization does the obligation rest to provide this medium as it does upon the American Society of Agronomy.

The sum of $1,000 per annum should prove sufficient to cover the cost of publication and of the current expenses of the Society. Three hundred and fifty members and a subscription list of 150 copies would provide this sum, aside from any revenue derived from advertisements. With a present membership of over 200 and an additional eligible constituency of between 300 and 400 men, the increasing of our membership to 350 or 400 ought to prove a comparatively easy matter. The object is worthy of the attention and the best effort of the Society.[2]

## 5. MINUTES OF THE FOURTH ANNUAL MEETING, COLUMBUS, OHIO, NOVEMBER 13–14, 1911.

### First Session, Monday Forenoon, November 13.

The meeting was called to order by President Wheeler at 10 A.M., in the assembly room of Ohio Union. Members were asked to register and obtain badges. Others present desiring membership in the Society were invited to join. Professor A. G. McCall, of Ohio University, offered the privileges of Ohio Union to all in attendance at the meeting.

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[2] At the business session the Executive Committee was instructed to consider the publication of a journal and report at the next annual meeting.—Secretary.

The regular program was then taken up and the following papers presented.

"Preliminary Report on the Field Study of Soil Moisture," by Professor A. G. McCall, Ohio State University. The paper was discussed by Professor E. G. Montgomery.

"The Application of Wilting-coefficient Determinations in Agronomic Investigations," by Dr. Lyman J. Briggs and Dr. H. L. Shantz, U. S. Department of Agriculture. This paper, illustrated with lantern slides, was read by Professor G. N. Coffey and discussed by Mr. R. O. E. Davis of the Bureau of Soils.

At this point President W. O. Thompson of Ohio University was given the floor and offered the accommodations of Ohio Union to the Society, outlined the schedule of meetings of the various societies, and invited the members of our Society to attend the reception to be given on Thursday evening. By vote of the Society it was decided not to change the place of meeting for the evening sessions scheduled for Ohio Union. The reading of papers was then continued, as follows:

The paper entitled "Practical Classification of Soils," by Professor E. O. Fippin of Cornell University, was withdrawn[3] by the author to avoid any possible anticipation of the report of the Committee on Soil Classification and Mapping.

"Instruction in Farm Crops," by Professor M. L. Fisher, Purdue University.

On motion is was decided to receive and hear a paper[4] entitled "Physical Properties of Soils as Affected by Soluble Salts," by Mr. R. O. E. Davis, U. S. Bureau of Soils, which was then presented by the author.

The following committee appointments were then made by the President:

### NOMINATING COMMITTEE.

E. O. Fippin, Cornell University,
W. M. Jardine, Kansas Experiment Station,
M. L. Fisher, Purdue University.

### AUDITING COMMITTEE.

L. A. Clinton, Storrs Experiment Station,
G. N. Coffey, Ohio Experiment Station.

An adjournment was then taken until the afternoon session. Forty-six persons were in attendance at the morning session.

### SECOND SESSION, MONDAY AFTERNOON, NOVEMBER 13.

The meeting was called to order by President Wheeler at 2:30 P.M., in the Ohio Union, and the presentation of papers resumed, as follows:

"The Use of Small Plats in Field Experiments," by Dr. T. L. Lyon. The paper was discussed by Dr. Wheeler and Professor Zavitz.

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[3] This paper was afterward submitted for publication and appears in this volume.—SECRETARY.

[4] Published as Bulletin 82 of the U. S. Bureau of Soils.—SECRETARY.

"The Pure-line Method of Breeding Drought-resistant Cereals," by Mr. Cecil Salmon, U. S. Department of Agriculture. The paper was discussed by Director R. W. Thatcher.

"Standardizing plats,"[5] by Professor E. G. Montgomery, Nebraska Experiment Station. The paper was illustrated by lantern slides. Discussion was made by Dr. Lipman and Director Thorne.

"Varietal Nomenclature in Cereals,"[6] by Professor E. G. Montgomery, Nebraska Experiment Station.

On motion a committee of three to consider plans for standardizing nomenclature was ordered appointed. The appointment was deferred for action of the new President.[7]

On motion it was ordered that the Association of Official Seed Analysts be invited to coöperate.

On motion Director R. W. Thatcher was requested to deliver his paper at this session and the following was presented:

"The Relation of Rainfall to the Protein Content of Wheat," by Director R. W. Thatcher, Washington Experiment Station.

The paper entitled "The Water Requirements of Crop Plants in Eastern Colorado," by Doctors L. J. Briggs and H. L. Shantz, U. S. Department of Agriculture, was read by title only.

On motion a committee of two, Professor A. G. McCall and Secretary C. R. Ball, was appointed to arrange, if possible, for the holding of the morning session of Tuesday at some point downtown, to permit easy access to the Hartman Farm on a proposed excursion.

## Third (Joint) Session, Monday Evening, November 13.

A joint session of the Society for the Promotion of Agricultural Science and the American Society of Agronomy was held in the Ohio Union, for the delivering of presidential addresses. The meeting was called to order at 8 P.M., by Dr. H. P. Armsby, President of the American Society of Animal Nutrition, who had been selected to preside. The following addresses were read:

"Governmental Promotion of Agricultural Science," by Professor S. M. Tracy, President of the Society for the Promotion of Agricultural Science.

"The Status and Future of the American Agronomist," by Dr. H. J. Wheeler, President of the American Society of Agronomy.

The committee appointed to obtain a meeting place in town for the morning session on Tuesday, reported that the session would be held in the Southern Hotel at 9 A.M.

Adjournment was then taken until that hour. Seventy-five persons were in attendance at this session.

## Fourth (Business) Session, Tuesday Morning, November 14.

The session was opened at 9:30 A.M., in Room B of the Southern Hotel, by Vice-President C. A. Zavitz, President Wheeler being temporarily absent in attendance upon another meeting.

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[5] Withdrawn for publication by the Nebraska Experiment Station.—Secretary.

[6] Withdrawn in anticipation of a report from the Committee on Standardizing Nomenclature, noted below.—Secretary.

[7] President Thatcher subsequently appointed E. G. Montgomery, chairman, A. G. McCall and W. M. Jardine as members of this committee.—Secretary.

The two remaining program papers, previously passed over, were not present and were read by title only, as follows:

"Methods of Teaching Farm Organization," by Hon. W. M. Hays, U. S. Department of Agriculture.

"Methods of Determining the Relative Yields of Varieties of Field Crops,"[8] by Professor A. T. Wiancko, Purdue University.

The minutes of the preceding meeting were read by the Secretary and approved.

The report of the Treasurer, Professor Lyman Carrier, was read by the Treasurer, and, on motion, was accepted.

The report of the Auditing Committee was read by the chairman, Dr. L. A. Clinton, and, on motion, accepted.

The report of the Secretary, Mr. Carleton R. Ball, was read by the Secretary, and, on motion, accepted.

The report of the Nominating Committee was read by the chairman, Professor E. O. Fippin, placing in nomination the following members for the offices named:

*President,* Professor R. W. Thatcher.
*First Vice-President,* Professor C. A. Mooers.
*Second Vice-President,* Dr. L. A. Clinton.
*Secretary,* Mr. Carleton R. Ball.
*Treasurer,* Professor A. G. McCall.
*Program Committee,* Professor M. F. Miller and Mr. F. D. Farrell.

By motion the Secretary was instructed to cast the ballot of the Society for the nominees, on which they were declared elected to the respective offices.

The report of the Committee on Constitution and By-Laws was read by the chairman, Dr. T. L. Lyon, proposing three amendments to the constitution and one to the by-laws, notice to members having been given more than ten days previously.

By consent the committee was permitted to insert the words "and associate" after the word "active" in line 9 of Article IV.

On motion the proposed amendments (printed in full in Report of Committee on Constitution) were then adopted in toto.

The Committee on Soil Classification and Mapping reported through its chairman, Professor G. N. Coffey, that owing to the difficulty of meeting together it was not ready to present an official report, but hoped to prepare one soon. Moved by Dr. Lyon that the report be published in the PROCEEDINGS in advance of presentation. Moved by Mr. Marbut in substitution that copies of the report be distributed to members of the Society before May 1, 1912, but not printed in the PROCEEDINGS. The substitute motion carried.

On motion the Executive Committee was empowered to appoint, in consultation with the chairman, five members[9] on the Committee on Soil Classification and Mapping to succeed the two-year members whose terms of service expire in 1911.

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[8] Withdrawn until additional data are obtained. A paper entitled "The Inheritance and Effect of Sucker Production in Corn," substituted and published in this volume.—SECRETARY.

[9] The following were appointed for a period of three years: F. J. Alway, R. H. Loughridge, C. F. Marbut, C. A. Mooers, J. G. Mosier.—SECRETARY.

The question of taking part in a previously approved excursion to the Hartman Farm being raised at this point, the Society, on motion, decided to proceed with its business session and expressed its regrets to the farm manager through Professor A. G. McCall.

The report of the Committee on Affiliation of Agricultural Societies was read by the secretary of the Committee, Mr. Carleton R. Ball, as printed on pages 27 to 31 of Volume 2 of the PROCEEDINGS. It was moved and seconded to substitute fifty cents for one dollar as the maximum assessment per member in Article VII of the proposed constitution. After discussion the motion was withdrawn.

On motion, the report of the Committee was accepted and its recommendation that the proposed constitution of the Affiliated Societies of Agricultural Science be adopted, was approved, and the American Society of Agronomy declared an adhering society of the affiliation, if completed.

On motion our member of the Council of the Affiliated Societies was instructed to offer in Council an amendment substituting fifty cents for one dollar as the maximum pro rata assessment per member by the Council.

Dr. H. J. Wheeler was nominated for member of the Council of the Affiliated Societies and unanimously elected.

For the Committee on Standardization of Field Experiments the Secretary of the Society expressed the regrets of Chairman C. V. Piper that his prolonged absence abroad had prevented the preparation of a report. On motion the Committee was continued.

For the Committee on Agronomic Terminology, the chairman, Mr. C. R. Ball, reported that his duties as Secretary and Editor had prevented any attention to this subject during the year. On motion the committee was continued.

The report of the Committee on Publication was presented by its Secretary, Mr. Carleton R. Ball, and accepted and the Committee discharged.[10]

On motion the Secretary was authorized to publish by title only all program papers not received from authors before January 1, 1912.

On motion the Secretary was authorized to publish in the PROCEEDINGS any papers not presented before the Society if received before January 1, 1912, and approved by the Committee on Publication, provided the expense of such publication be not greater than, in the judgment of the Executive Committee, the funds of the Society will warrant.

Moved and carried to publish by title papers presented by members of other Societies at joint sessions in which this Society took part.

On motion the Society adopted for citations in its PROCEEDINGS the form of abbreviation used in the Experiment Station Record.

On motion the Executive Committee was instructed to consider the publication of a journal and report at the next annual meeting.

On motion any other matters needing attention were referred to the Executive Committee with power to act.[11]

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[10] A new Committee on Publication was subsequently appointed, with members as follows: C. V. Piper, chairman, T. L. Lyon and C. R. Ball.

[11] The new Executive Committee met at Ohio Union at 6:30 Tuesday evening, November 14, to consider matters affecting the Society. The following resolution was adopted "That the President and other officers of Ohio State University, in providing a meeting place for the Society, in extending the

On motion the Society adjourned its session, at which about 35 members were present.

### Fifth (Joint) Session, Tuesday Afternoon, November 14.

This joint session was participated in by four societies, namely,

American Society of Agronomy,
American Society of Animal Nutrition,
Society for the Promotion of Agricultural Science, and
American Farm Management Association.

The session was opened at 2 P.M., with Dr. A. C. True presiding. The following papers were presented under the symposium subject, "Improvement in Methods of Agricultural Investigation."

"Methods in Nutrition Investigation," by Dr. E. B. Forbes, Ohio Experiment Station, representing the American Society of Animal Nutrition.

"The Feeding Experiment; Its Improvement and Refinement," by President H. J. Waters, Kansas Agricultural College, representing the Society of Animal Nutrition.

"The Biological Factor in Soil Investigation," by Dr. Jacob G. Lipman, New Jersey Experiment Station, representing the Society for the Promotion of Agricultural Science.

"Methods of Studying the Relation of Water to Plant Production," illustrated by lantern slides. Professor E. G. Montgomery, Nebraska Experiment Station, representing the American Society of Agronomy.

"Methods of Reducing Error in Field Experiments," illustrated by lantern slides. Dr. T. L. Lyon, Cornell University, representing the American Society of Agronomy.

The Society then adjourned until evening. About 100 persons attended this joint session.

### Sixth (Joint) Session, Tuesday Evening, November 14.

For this session the American Society of Agronomy, the Society for the Promotion of Agricultural Science and the American Society of Animal Nutrition were invited to meet with the American Farm Management Association, but were not represented on the program. The topic was: "What is farm management and what will be its contribution to agriculture?"

The closing of this session automatically adjourned the Society *sine die*, subject to the call of the Executive Committee.

A true copy, respectfully submitted.

Carleton R. Ball,
*Secretary.*

## 6. COMMITTEES FOR 1912.

The Society was represented by nine committees during 1911. Six of these, namely, the Committees on Affiliation, Audit, Constitution and By-Laws, Nominations, Program, and Publication, were discharged on the completion of their

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privileges of Ohio Union to its members and in rendering various other services, contributed largely to the success of the meeting and the thanks and hearty appreciation of the Society are hereby tendered them for this courteous assistance."

labors and acceptance of their reports. New Committees on Program and Publication were selected. Two others, the Committees on Standardization of Field Experiments and on Terminology, were continued without change. The Committee on Soil Classification and Mapping is a permanent committee of fifteen members, of whom five are appointed each year to succeed those whose terms expire. One new committee of the Society was created, by motion, namely, a Committee on Varietal Nomenclature. The personnel of these six committees is as follows:

### Executive Committee.

President R. W. Thatcher,
Vice-President C. A. Mooers,
Vice-President L. A. Clinton.
Secretary C. R. Ball,
Treasurer A. G. McCall.

### Committee on Program.

M. F. Miller, *Chairman;* F. D. Farrell.

### Committee on Publication.

C. V. Piper, *Chairman;* T. L. Lyon, C. R. Ball.

### Committee on Soil Classification and Mapping.

*Members, 1910–1912.*

G. N. Coffey, *Chairman;* F. T. Shutt, C. E. Thorne,
H. J. Wheeler, A. R. Whitson.

*Members, 1911–1913.*

Wm. H. Day, E. O. Fippin, G. S. Fraps,
Alvin Keyser, B. W. Kilgore.

*Members, 1912–1914.*

F. J. Alway, R. H. Loughridge, C. F. Marbut,
C. A. Mooers, J. G. Mosier.

### Committee on Standardization of Field Experiments.

C. V. Piper, *Chairman;* E. G. Montgomery. W. H. Stevenson.

### Committee on Terminology.

Carleton R. Ball, *Chairman;* C. G. Hopkins, J. F. Duggar.

### Committee on Varietal Nomenclature.

E. G. Montgomery, *Chairman;* A. G. McCall, W. M. Jardine.

## REPORT OF THE TREASURER.

I have the honor to make the following report as Treasurer of this Society for the year 1911.

### RECEIPTS.

| | | | |
|---|---|---|---|
| From C. R. Ball, Secretary, Dec. 14, 1910 | | $100.00 | |
| From L. H. Smith, former Treasurer, Jan. 5, 1911 | | 500.71 | |
| From C. R. Ball, Secretary, Jan. 23, 1911 | | 100.00 | |
| From C. R. Ball, Secretary, Feb. 13, 1911 | | 100.00 | |
| From C. R. Ball, Secretary, Apr. 10, 1911 | | 23.40 | |
| From C. R. Ball, Secretary, July 19, 1911 | | 24.00 | |
| From 107 members, dues for 1911 | per list attached | 214.00 | |
| From 8 members, dues for 1912 | | 16.00 | |
| For 1 copy PROCEEDINGS, Volume 1 | | 2.00 | $1,080.11 |

### DISBURSEMENTS.

| | | | |
|---|---|---|---|
| 1910. | | | |
| Dec. 14, | Judd & Detweiler, reprints | $ 35.00 | |
| Dec. 14, | L. M. Thayer, printing | 17.00 | |
| Dec. 14, | C. R. Ball, postage, supplies and clerical help | 26.05 | |
| Dec. 30, | C. R. Ball, postage, supplies and clerical help | 12.40 | |
| 1911. | | | |
| Jan. 5, | L. Carrier, express | 1.30 | |
| Apr. 10, | Judd & Detweiler, printing and binding Vol. 1 | 527.70 | |
| Apr. 10, | C. R. Ball, postage, supplies and clerical help | 15.50 | |
| May 14, | L. Carrier, 500 stamped envelopes | 10.62 | |
| Aug. 22, | Maurice Joyce Eng. Co., engravings | 46.20 | |
| Nov. 4, | C. R. Ball, postage, supplies and clerical help | 30.76 | |
| Nov. 6, | Miss Chewning, clerical help | .70 | |
| Nov. 7, | C. H. Crabill, clerical help | 1.25 | $ 724.48 |
| | Balance on hand Nov. 6, 1911 | | $ 355.63 |

Respectfully submitted,

LYMAN CARRIER,
*Treasurer.*

### AUDITORS' STATEMENT.

This report has been examined and we find the same correct.

L. A. CLINTON,
GEO. N. COFFEY,
*Auditing Committee.*

November 13, 1911.

# REPORTS OF COMMITTEES.

## REPORTS FOUND IN THE MINUTES OR ELSEWHERE.

Nine committees have been in existence during all or part of the year. No official reports were presented by the following committees, as noted in the minutes of the business session: Committee on Soil Classification and Mapping, Committee on Standardization of Field Experiments, Committee on Terminology. The report of the Committee on Nominations will also be found in the minutes of the business session. The report of the Auditing Committee follows the Treasurer's Report. The Program Committee made no formal report, other than the printed program.

The reports of the Committee on Affiliation of Agricultural Societies, Committee on Constitution and By-Laws, and Committee on Publication are given below.

## REPORT OF COMMITTEE ON AFFILIATION.

The report of this committee was printed in full, with recommendations, on pages 27 to 31, inclusive, of volume 2 of our PROCEEDINGS. As noted in the minutes, it was read before the Society and the recommendation that the proposed constitution of the Affiliated Societies of Agricultural Science be adopted was approved by a vote of the Society. Dr. H. J. Wheeler was elected our representative in the Council.—SECRETARY.

## REPORT OF COMMITTEE ON CONSTITUTION AND BY-LAWS.

Your Committee on Constitution and By-Laws presents for action the four proposed amendments which were sent to the membership for consideration in the following form and recommends their adoption.

"ITHACA, N. Y., Nov. 1, 1911.

"*Dear Sir:*

"The Committee on revision of the Constitution of the Society recommend the following changes in certain articles and in accordance with the provisions of Article IX herewith present the proposed changes for your consideration before submitting them to a vote of the Society at the meeting to be held in Columbus, Ohio, on November 13 and 14, 1911.

"1. Change Article IV (Membership), now reading:

"'Membership shall be of two kinds, active and associate. Active membership shall be limited to persons who are engaged in teaching agronomy, or in scientific investigation in some branch of agronomy. Associate membership shall be composed of other persons interested in the object of the Society. Associate members shall be entitled to all privileges of the Society except that of voting. Active membership may be secured by the endorsement in writing of one active member and upon approval by the President and Secretary and payment of the annual dues.'

to read:

"'Membership shall be of three kinds, active, associate and local. Active membership shall be limited to persons who are engaged in teaching agronomy or in scientific investigation in some branch of agronomy. Associate membership shall be composed of other persons interested in the object of the Society. Associate members shall be entitled to all the privileges of the Society except that of voting. Local members shall have no vote in the Society and shall not be entitled to a copy of the printed proceedings without payment of an extra sum of money as provided in Article V of this Constitution.'

"'Active and associate membership may be secured by the endorsement in writing of some active member and upon approval by the President and Secretary and payment of the annual dues.'

"'Members who take up residence outside of North America may retain their their membership on the same terms as members living in America.'

"2. Change Article V (Local Sections), now reading:

"'Any three members may, with the approval of the Executive Committee, organize a local section of ten or more persons, making its own rules for associate membership, providing its members shall become active or associate members of the Society.'

to read:

"'Any three members may, with the approval of the Executive Committee, organize a local section of ten or more persons who, if not already members of the Society, may become active or associate members on application and payment of regular dues for such membership. Local sections may make their own rules for membership, provided that for each member who does not become an active or associate member of the Society the local section shall pay to the Society a fee of fifty cents, which shall make such person a local member of the Society and entitled to purchase its PROCEEDINGS for a sum not to exceed the difference between a local member's fee and the annual dues for active membership, but shall not entitle him to a vote in the Society. Any local section may be dissolved by a majority vote of members present at any regular meeting of the Society.'

"3. Add to Article IX (Amendments):

"'The Executive Committee may propose amendments at any time between meetings and the same shall be accepted or rejected by a two-thirds vote of the members who mail their ballots within thirty days after the notice of the proposed amendments was sent to them. Any twenty members may initiate a proposed amendment, which shall then be submitted by the Executive Committee to a vote of the Society.'

"4. Amendment to By-Laws. Change By-Law 1, now reading:

"'The annual dues for each active and associate member shall be $2, which shall be paid on or before April 1 of the year for which membership is held.'

to read:

"'The annual dues for each active and associate member shall be $2, and for each local member $.50, which shall be paid on or before April 1 of the year for which membership is held.'

T. L. LYON,
C. R. BALL,
C. V. PIPER,
*Committee.'"*

(The amendments proposed above were adopted. The entire constitution and by-laws, as amended, is printed elsewhere in this volume.—EDITOR.)

## REPORT OF COMMITTEE ON PUBLICATION.

The Committee on Publication feel certain that greater uniformity can be obtained and the labor of editing manuscripts very much reduced through coöperation on the part of the authors. In order to make specific the lines along which coöperation is desired, the following suggestions are respectfully made.

1. *Text in General.*—All manuscripts should be typewritten and only original copies submitted for publication. Carbon copies cannot be used. Care should be taken that the manuscript is correct in all particulars. In making a final copy it not infrequently happens that a word is omitted, that a proper name is misspelled, that punctuation marks are omitted or incorrectly used, and that mistakes occur in tables and citations. All manuscripts should be given a careful final reading to eliminate such errors as these. All corrections should be legibly made in ink and the exact place of insertion of any added matter should be plainly indicated.

2. *Headings.*—Headings and subheading should be consistently used and their comparative ranks should be accurately shown by means of capitals and lowercase type and by different underscorings of these. Titles, as well as other headings, should be made as brief as is possible without sacrificing clearness.

3. *Tables.*—All tables should be numbered consecutively in Roman figures. This number should be written above the table and be followed by the proper heading or description of the table, as, for instance,

"Table VI.—Average Moisture Content Under Continuous Cropping and Range."

Indicate on the margin of manuscript the point in the text where it is desired to have each table inserted, if they are not so written. Make the proper reference in the text to all tables.

4. *Illustrations.*—All text figures should be numbered consecutively in arabic numerals. The number and description or legend of the illustration should be written below it, as follows:

"Fig. 5.—Specimen page of Michigan alfalfa-breeding register."

The other suggestions given concerning tables apply also to illustrations.

5. *Citations of Literature.*—All citations should be in the form of footnotes and not inserted in parentheses in the text. Such footnotes should be indicated by consecutive arabic figures. This is preferable to indicating them by letters or by such symbols as the asterisk, etc. Full citations of each paper should be given, including the author, the title, and the journal in which published. The author's name should be written with the surname first, followed by the initials. The title of the paper is written in full, capitals being used only on the initial word and on proper names. In citing the journal or place of publication, the abbreviated name of the journal comes first, followed by the volume number from which the included pages are separated by a colon. Then follows reference to the illustrations and, finally, the date. If the year which the volume covers is not the year in which it was issued, the first date should be placed in parentheses followed by the year in which the volume was actually published. The following are examples of complete citations as recommended above:

"[1] Fippin, Elmer O. Some causes of soil granulation. Proc. Am. Soc. Agron. 2: 106–121. figs. 11–18. (1910) 1911.

[2] Watt, R. D. Nitrification in Transvaal soils. Transvaal Agric. Jour. 7: 202–205. 1909."

For the Committee,

C. R. Ball,
*Secretary.*

# CONSTITUTION AS AMENDED NOVEMBER 14, 1911.

### *Name.*

*Article I.* The name of this organization shall be The American Society of Agronomy.

### *Object.*

*Article II.* The object of the Society shall be the increase and dissemination of knowledge concerning soils and crops and the conditions affecting them.

### *Charter Members.*

*Article III.* All persons expressing a desire to join the Society and paying the annual dues before July 1, 1908, shall be charter members.

### *Membership.*

*Article IV.* Membership shall be of three kinds, active, associate and local. Active membership shall be limited to persons who are engaged in teaching agronomy or in scientific investigation in some branch of agronomy. Associate membership shall be composed of other persons interested in the object of the Society. Associate members shall be entitled to all the privileges of the Society except that of voting. Local members shall have no vote in the Society and shall not be entitled to a copy of the printed proceedings without payment of an extra sum of money as provided in Article V of this Constitution.

Active and associate membership may be secured by the endorsement in writing of some active member and upon approval by the President and Secretary and payment of the annual dues.

Members who take up residence outside of North America may retain their membership on the same terms as members living in America.

### *Local Sections.*

*Article V.* Any three members may, with the approval of the Executive Committee, organize a local section of ten or more persons who, if not already members of the Society, may become active or associate members on application and payment of regular dues for such membership. Local sections may make their own rules for membership, provided that for each member who does not become an active or associate member of the Society the local section shall pay to the Society a fee of fifty cents, which shall make such person a local member of the Society and entitled to purchase its PROCEEDINGS for a sum not to exceed the difference between a local member's fee and the annual dues for active membership, but shall not entitle him to a vote in the Society. Any local section may be dissolved by a majority vote of members present at any regular meeting of the Society.

### *Officers.*

*Article VI.* The officers shall consist of a President, a First Vice-President, a Second Vice-President, a Secretary, and a Treasurer, which officers shall constitute the Executive Committee.

### *Duties and Term of Office.*

*Article VII.* The duties of these officers shall be those usually pertaining to their respective offices. Their term of office shall be for one year, or until their successors shall have been elected.

### *Meetings.*

*Article VIII.* When not determined by vote of the Society, the time and place of meetings shall be decided by the Executive Committee.

### *Amendments.*

*Article IX.* This constitution may be amended by a two-thirds vote of the members present at any regular meeting, announcement of the proposed amendments having been made at least ten days before such meeting.

The Executive Committee may propose amendments at any time between meetings and the same shall be accepted or rejected by a two-thirds vote of the members who mail their ballots within thirty days after the notice of the proposed amendments was sent to them. Any twenty members may initiate a proposed amendment, which shall then be submitted by the Executive Committee to a vote of the Society.

### *By-Laws.*

1. The annual dues for each active and associate member shall be $2, and for each local member $.50, which shall be paid on or before April 1 of the year for which membership is held.
2. Any member in arrears for dues for more than one year shall thereby forfeit membership, but may be restored to membership without action of the Society upon the payment of such arrears.
3. One meeting of the Society shall be held every year if practicable.
4. A quorum at any meeting shall consist of fifteen members.
5. Money shall be paid by the Treasurer only upon the written order of the Secretary.
6. These by-laws may be amended by a two-thirds vote of the members present at any regular meeting.

# SCIENTIFIC SECTION.

## THE STATUS AND FUTURE OF THE AMERICAN AGRONOMIST.[1]

### PRESIDENTIAL ADDRESS AT THE COLUMBUS MEETING, 1911.

H. J. Wheeler,

Experiment Station of the Rhode Island State College, Kingston, R. I.

On the occasion of this fourth annual meeting of the American Society of Agronomy it is of interest to note that our membership has now grown to more than two hundred and that our published proceedings are finding their place not only in the private libraries of American agronomists, but also on the shelves of the libraries of the leading colleges and universities of the country. Indeed, the time seems to have arrived when this society should seriously consider supporting a journal. We have definitely put our hands to the plow. It behooves us, therefore, to be diligent, to push this society into the front rank of the scientific societies of the land, and to guard jealously against any and all influences which may interfere with the highest development of its individual members and thereby restrict its opportunity for public usefulness.

It must be recognized that no scientific body can be brought to its highest plane nor be made of the greatest service to our American people unless the ideals of its individual members are high. The future of agronomy in this country is, however, not only dependent upon such ideals, but also, in a very great degree, upon the administrative attitude of the institutions which we serve.

To the professor who, a generation ago, was covering in his way the whole range of agricultural science, the field of the present-day agronomist may seem narrow; but those who have kept pace with the march of recent events must be impressed with its breadth and by the fact that even greater specialization is foreshadowed in the near future, when the subject of agronomy may readily resolve itself into several distinct fields of effort.

The student of farm crops can no longer be content with a knowledge of what belongs to the art of crop production, but must now be well grounded in systematic botany, especially in its relation to the bacteria and fungi, and to the plant families which embrace the weeds, grasses and the common farm crops. He should understand and follow the work in breeding which is being done throughout the world.

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[1] Printed also in Science, n. ser., 35: 81–87, Jan. 19, 1912.

In order to deal with many of the problems with which he will be confronted as an investigator and which he should be able to fully grasp as a teacher, fundamental training in physiological botany becomes essential. Indeed, this is only the beginning, for the agronomist has not only to deal in detail with the plants which contribute directly to the food supply of man and of our domestic animals, but also with an extensive soil flora almost undreamed of a half century ago, upon the study and control of which, for the furtherance of agriculture, the world is today barely entering. The agronomist of the future must not only deal with the effect of these soil plants upon each other and upon the higher plants in their parasitical and symbiotic relations, but also as producers of ammonia and nitrates, and as destroyers of compounds of sulfur and of nitrogen within the soil.

As suggested by the recent investigations of soil amebæ by Russell and Hutchinson at Rothamsted, he must also deal with microscopic animal denizens of the soil which may militate against, or, as perhaps may yet be found, aid in the growth of certain beneficial fungi, and other microscopic flora. In fact, the end is not yet, for chemistry now plays its rôle in furnishing the agronomist toluene, carbon bisulfid, and other substances for combating unfavorable animal life in the soil. Chemistry also plays its part in controlling and regulating the chemical reaction, and hence the dominance or decadence of various types or even of individual representatives of the soil flora.

There is reason to believe that we are today but entering upon the study of the organisms and of the conditions best suited to ensure the assimilation of atmospheric nitrogen by non-symbiotic means.

The whole question of the use of fertilizers and of their action is daily becoming more complex. It was a simple proposition when one supposed that it was merely essential to learn what elements crops removed from the soil and then to supply a proper part thereof, without special reference to the particular compounds used to supply them. Today, cognizance must be taken of the effect of the associated compounds. The sulfuric acid and chlorin combined with ammonia in ammonium sulfate and ammonium chlorid may have a highly toxic effect from the outset, or such effects may soon develop in certain soils if care is not taken to maintain a proper basic condition. The subsequent effect of organic nitrogenous manures is quite different on some soils from that of nitrate of soda. Even though the avoidance of chlorin and sulfuric acid, when combined with ammonia, is of vital importance under certain circumstances, it is often less necessary under the same conditions if they are in combination with potassium, calcium and magnesium. For still other crops, or on another soil, they may nevertheless be used with good effect.

Another illustration is afforded by nitrate of soda. The residual effect of repeated annual applications may result in the most marked soil improvement, rendering successful the cultivation of a whole series of crops where they could not be grown successfully before. The same treatment, even for a long series of years, may still fail to correct the existing soil conditions enough for other groups of plants. The continued use of nitrate of soda on another soil may cause it to become puddled until it is rendered practically unfit to be a habitat for most agricultural plants. For certain plants, such as the radish and beet, the residual sodium from nitrate of soda may perform valuable physiological functions which would be lacking, or of slight importance, in connection with certain other plants. Raw rock phosphate may be valuable as a fertilizer on the black soils of the Illinois corn-belt and for crops usually grown there, but for the light sandy soils of the Atlantic coast, and for certain trucking crops its use at prevailing prices could perhaps not be recommended. To add to this complexity certain text-books proscribe the use of lime with superphosphates, or on soils where undissolved phosphates are to be used, and yet there may be soils on which liming is essential to the most economical use of each. It is, in fact, not enough that the agronomist should bear in mind and master all of these details, but now he is called upon to consider the specific requirements, for lime and other substances, of hundreds of varieties of plants. He must also consider the alleged toxic root excreta and methods for rendering them innocuous, and he must take cognizance of the catalytic action of manganese and other elements not heretofore grouped in the galaxy of fertilizers and soil amendments. He must now consider the effect of legumes and other plants upon those growing in association with them and the effect of given crops upon those which follow. The whole question of maintaining conditions favorable to nitrification is of prime importance in certain sections of the United States and in this connection chemistry is again the handmaid of agronomy; yet in certain of the semi-arid regions of the middle west excessive nitrification is said to have become a scourge which is wiping out many of the most promising orchard industries. It must be evident that the agronomist must therefore be something of a climatologist, for in certain of these features the weather conditions are the chief governing factors.

The successful agronomist must also deal effectively with a host of plant parasites which may attack the roots, the base of the stems, or the other aerial parts of the plants. Some of these may be killed by poisons whereas others cannot. Even the sucking and boring insects furnish a problem in themselves, long after the entomologist has determined the essential features of their life history. Just as "every animal has its fleas and these have fleas to bite 'em," so the plants have their many animal and fungus parasites, with which the agronomist is forced to deal.

Since the soil is one of the chief concerns of the agronomist, and it is known to be teeming with many forms of microscopic life of beneficial or injurious character, it is important to take cognizance of the possible effect upon this life of the various kinds of organic matter and of fertilizers which may be introduced into the soil from time to time.

Notwithstanding the recent assertion that practically the same minerals are found in all soils, that plants feed from very weak solutions, and that the soil solution is being continually renewed, we cannot complacently fold our arms and watch the workings of the divine providence in the production of food for the human race; for some soils appear still to lack enough available plant food at certain stages of growth, and others give rise to conditions, naturally, which require chemical and physical amelioration. It is an incontrovertible fact that soils derived from given kinds of rocks have usually distinct needs, whereas such treatment may be wholly neglected in the case of soils derived from rocks of a different character. For these and other obvious reasons the agronomist, in order to be well equipped to meet situations which may arise in another state, or in a new position to which he may be called, will find it of distinct aid if his fundamental educational equipment includes geology, mineralogy, and physics in its special application to the many problems of the soil.

The agronomist will be brought face to face with emergencies and questions involving physical chemistry, the foundation for which is supplied not only by general chemistry but also by knowledge of mathematics involving the calculus.

Finally, above and before all should be placed the subject of English, the call for which in some station bulletins is obvious, and in the use of which none can be too proficient.

It may be argued that the fundamental educational requirements as presented encroach upon other domains of science, that they are too comprehensive and are more exacting than the conditions demand. Nevertheless our progress as agronomists cannot attain its maximum by depending wholly upon men who are trained only in a narrow specialty. Those engaged in given lines of agronomical research must have a sufficiently broad training in order to grasp the significance and bearing of factors lying frequently much outside of their strict domain. Had not Hellriegel possessed an outlook broader than that circumscribed by the mere limits of chemistry, it is problematical if the discovery of nitrogen assimilation through the intervention of micro-organisms might not have remained a problem for ourselves.

It is not enough that the teacher or investigator in agronomy be skilled in its art but he must be trained in all of the natural sciences which are closely related to crops, fertilizers, soil amendments and to soils themselves in all of their several relations. The man who looks forward to service in the west or middle west, cannot neglect the chemistry of fertilizers in their relation to the special crop and to the special soil, for the fertilizer problem is advancing westward at a rapid rate and many of the present-day needs of the east will, in the near future, become the needs of much of the west and middle west.

From what has been said it must be obvious that the ordinary college course cannot be considered an adequate preparation for the life work of the agronomist, whether he be engaged in teaching or in research, but that this must be supplemented by at least three years' work at the university. Conversely, it must be equally obvious that he who would succeed in the fullest degree in his scientific achievements in the domain of agronomy must also be familiar with the subject as an art, and if this knowledge was not acquired at home on the farm, before the beginning of the college course, it should surely be made a part of his equipment before entering upon the university course.

The demands of the times make imperative not only a knowledge of the art of agronomy and the possession of the foundation contributed by the college and university, but they demand that the teacher or investigator keep continually in touch with the work of others in this and other countries, and to this end a reading knowledge of French and German, and if possible of other foreign languages, is essential. The argument that it is sufficient to merely read the abstracts of papers is specious. The investigator should never be content with anything short of the original, since ideas as to the relative importance of the different parts of an investigation are often widely variable, dependent upon the outlook or particular experience of the abstractor. It, therefore, not infrequently happens that a point which may be passed over as insignificant is vital to the work of some investigator, who, if confined solely to consulting the abstract, might never be able to profit by it.

It is obvious that the teacher must have sufficient time at command for daily recreation if he expects to maintain himself in condition to present his subject matter year after year to his classes in a clear and forceful manner. The same thing is necessary for the investigator in order that he may be keen and alert in the pursuit of his problems. He is then in condition to recognize points of attack which the man pressed and wearied with many duties might pass by unnoticed. To him who would be a strong, full man, capable of imparting inspiration to his students or of attacking problems of research with the true enthusiasm which is essential to success, time must not only be allowed for renewal of physical strength and for abundant reading, but *also for undisturbed and consecutive thought.* This means that no institution can long expect to be a leader in the field of education or in research, if its policy is to demand so much by way of other duties or so many hours of teaching that its employees can become leaders neither in thought nor in research in their chosen specialties. A university president, in a recent address, announced that those teaching at his institution were hereafter to be measured for their fitness by their output in research. Such a policy, while prompted by a commendable spirit, might be more nearly applicable in a new institution in which the teaching demands are reasonable, but it is likely to work the grossest injustice if applied immediately in a college where worthy professors have grown old in a treadmill of exacting service, which has left no time for gathering inspiration, nor for work of research. Such men, if given the opportunity at the right time might have won a national or world-wide reputation as investigators, for they may have been original, diligent and fired with an enthusiasm which the institution itself gradually smothered and snuffed out. Such men should not be cast aside like an exhausted sponge, for the institution and the state owe them a debt which they cannot repay. Again, a college professor cannot always do his best work if made to feel that his tenure of office depends upon his yearly output in research. Such avowed watchfulness by a president or by a committee on efficiency is likely to lead to superficiality, to hasty publication, or to create unrest disastrous to research of a high order and to bring many disastrous consequences in its train.

Object lessons of spoiled investigators are especially common in many of the smaller colleges and even in many of the larger ones; yet the time may never come when it will be safe to measure the fitness of all men for college teaching solely, or even chiefly, by their research output. Nevertheless, one cannot but recognize the desirability of encouraging teachers to practice exhaustive reading on special subjects, or to undertake special advanced research, whenever the demands of their positions and the attendant circumstances render it possible.

From what has been said it would appear that all teachers, and those who are selected to conduct research, should have at least three years of university training superimposed upon the college foundation. In saying this the writer recognizes that some of the best men in the country have not had this experience, but yet have won an enviable reputation in their respective lines, even in certain cases outstripping many who have enjoyed a more extensive fundamental training. It must, nevertheless, be recognized that such men have succeeded not in consequence of their handicap, but in spite of it! They were close observers, diligent students, and were possessed of original and judicial minds.

Admitting that the university training is a great desideratum in all cases, the problem presents itself of lending sufficient encouragement to young men so that they will be willing to devote three of the best years of their lives, and a large sum of money, to university study.

At almost every session of the Association of American Agricultural Colleges and Experiment Stations some college or university president or station director has bemoaned the difficulty of finding adequately trained men to fill the higher positions, especially in research. Indeed, the Secretary of Agriculture, the Hon. James Wilson, has repeatedly stated in public addresses that the Department of Agriculture finds it impossible to secure in this country men adequately qualified for many of the positions in the federal service, on which account his department is forced to train its own men. This leads to the query: Why does not the same principle of supply and demand hold as in lines of industry? It is a fact, which I think will be disputed by none who are well informed, that this country furnishes exceptional opportunities today for the young man just out of college. Perhaps, indeed, if some of them, like men known to the writer, were forced to begin, after completing a four-year college course, at a salary of from $16 to $20 per month, all of which was required for board and clothes, they might be willing to make greater sacrifices than at present in order to insure for themselves a future, by securing a university training at whatever cost. Today, however, the young graduate can readily command an initial salary of from $800 to $1,200, and many have been advanced within from two to three years to salaries as great as, or greater than, those paid in other reputable colleges to much older and more experienced men who have enjoyed a university training.

When these young men look about them in the institutions with which they are connected they may even find others at the heads of departments who have never enjoyed graduate study. They may also find those who have made the sacrifice, struggling by all sorts of means to add enough to their insufficient incomes to enable them to support a small family, with few comforts, no luxuries, and even with deprivation and need before them, in case of unusual illness or misfortune. It is no wonder, under such circumstances, that he thinks "a bird in the hand is worth two in the bush" and prefers to go on accumulating, rather than to spend three years' time and the savings of other years in order to secure the mere intellectual advantage of further study. As I have several times pointed out in public addresses, there can be no permanent remedy for such a condition short of an assured pension for those who have given ten to fifteen years of efficient, faithful service to such colleges and stations, or there must be occasional half year intervals of freedom and a marked and progressive increase in compensation for the older and experienced men. As concerns pensions, one that does not become assured until the end of a thirty-year period of service, while a great boon to those who finally receive it and a welcome aid to the president in unloading undesired or superannuated professors, nevertheless fails to furnish that assurance of security in case of disability or later financial difficulties which encourages the professor to satisfactorily equip his library, to travel, to study and to surround himself by the broadening influences which are essential to his greatest intellectual development and to his greatest usefulness to the students who come under his instruction. In this matter of pensions and conditions surrounding them we have a valuable lesson to learn from Germany.

It has been argued by some that the early assurance of a pension robs the prospective recipient of initiative and enthusiasm in his chosen profession and encourages a letting up of his intellectual activities. To such as advance this argument the writer begs to enter an emphatic denial of the justness of the accusation, for from his personal acquaintance with professors in many of the leading German universities and his observation of their spirit of research, he is convinced of the utter incorrectness of such a position. Indeed, nowhere in the world could one find greater devotion to duty, greater willingness to make personal sacrifices, or greater zeal in investigation, than among the professors of these German universities, who can look forward complacently to the future if disabled, and in any event with the comfort and knowledge that their families, after their work is done, will be cared for properly as a reward for a lifetime of faithful public service.

Finally this society will do well to encourage the development in our universities of higher and broader graduate courses in the applied sciences related to agriculture. Let us use our influence as a body to secure from the Carnegie Foundation, for the teacher and investigator in the smaller land-grant colleges, the same fair and just recognition for quality and amount of public service rendered as is accorded to the teacher of mathematics or of the classics in the older classical colleges of the country. If necessary, let the American Society of Agronomy urge upon congress the provision of a pension system for the land-grant college, based upon a reasonable probationary limit of service as a condition for its becoming assured. If to this, these colleges will add the sabbatical year, or will allow a full half-year in every five, and will give adequate and progressive advances in salary with the years of service, we shall soon see plenty of young men fitting themselves well for the work of teaching and research.

In closing I would not fail to emphasize that young men entering our profession should do so with the missionary spirit and with the desire to serve their fellows uppermost in mind, but the situation today is such that many who set out with courage are forced, out of justice to their families and through failure to secure the reasonable comforts and necessities of life, to seek, against their will, such financial returns in other callings as are rarely the reward of the agricultural teacher and investigator.

# INSTRUCTION IN FARM CROPS.

M. L. Fisher,

Purdue University, Lafayette, Ind.

Farm crops, as a distinct and separate course of instruction, has but recently appeared in our college catalogues. An examination of the "write-ups" in the various college catalogues will show that, after making exceptions for local conditions, the courses are not uniform and not well organized. At a meeting like this, a free discussion of the subject ought to clarify our views and unify our ideas.

Farm crops are commonly considered to be those which are grown in field areas and usually include the various grain and forage crops, but they may also include certain others, which are certainly not grain or forage crops; for example, tobacco, cotton and other fiber crops, sugar cane, sugar beets, etc.

Before entering upon a course in farm crops, it is highly desirable that the student should have had a good course in agricultural botany. This course in botany should teach the fundamental things about the structure of the plant, its parts and their functions, the structure of the seed, and the use of the key in the identification of plants. It is also desirable that the course in farm crops be preceded or accompanied by an elementary course in soils.

The instruction in crops should comprise both class-room and laboratory work. The work in the class-room should give facts about the culture of crops and these facts should be based upon the results of good practice and exact experimentation. The work may be presented either in lectures or from text-books. At the present time there is no text which is entirely satisfactory.

The laboratory work should give practice in applying and observing some of the principles laid down in the class-room. There are also certain subjects which can not be well dealt with in the class-room and which need practice rather than discussion, for example, inspection of seeds for vitality and impurities, and the judging of grain and fibers.

Before beginning a discussion of the individual crops, there should be a few lectures or studies on the importance of good seed, the essentials for germination, the parts and functions of the plant, the classification of farm crops, and the principles of rotation.

In the class-room, attention should first be given to the staple crops of the state in which the institution is located, and later to crops not staple and to foreign crops. The staple crops may be further considered as (*a*) grain crops, and (*b*) forage crops. For the central states the grain crops include corn, wheat, oats, rye, and barley. While the potato is not a grain crop, it should also be included in this series of studies. Forage crops include clovers and grasses for hay and pasture, root crops, corn for forage, sorghum, soy beans, cowpeas, Canada field peas, millet, and rape.

Under crops not staple and foreign crops, may be considered such crops as rice, cotton and other fiber crops, tobacco, sugar cane, sugar beets, buckwheat, broomcorn, vetch, berseem, sanfoin, and many other not well known and not generally grown crops. Of course, in some states rice, cotton, tobacco, and sugar cane are staple crops. These should then be transferred to the first list.

The discussion of any crop should take account of its history, character of the plant, adaptation to soil and climate, preparation of seed bed, methods of planting, cultivation, and harvesting, varieties, and seed selection. Breeding should be treated only incidentally. Any course of instruction will give most attention and time to those crops which are of most immediate importance in the state.

The laboratory work should include: germination experiments, seed inspection and testing, studying clovers and grasses in the field, making weed seed collections and their study, studying mature plants of wheat, oats, rye, barley, emmer, spelt, and rice, moisture tests of grain, the scoring and comparative judging of grains and fibers, and field trips to study experimental plats. The work in the laboratory should be definitely outlined and assigned and each student should be expected to give a definite report of his work.

The amount of time given to a course in farm crops must of necessity vary. It may be expanded to maximum, or contracted to a minimum. The minimum is certainly not less than one semester of three class-room and two laboratory hours per week. This will barely suffice for the crops named in the class, "staple." Certainly two semesters are necessary to give a comprehensive course in crops, and if attention is to be given to breeding and technical work, a third semester is needed.

# THE RELATION OF PROTEIN CONTENT OF WHEAT TO RAINFALL.

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The results which I wish to present, very briefly, are an indirect outcome of a study of the chemical composition of Washington wheats which we have been carrying on at the State Experiment Station at Pullman, Washington, for the past five years. The complete data, as obtained in this study, have been published as Bulletins Nos. 84, 91, and 100, of the Station. It was only after the study was completed and the results tabulated and averaged that the definite relationships to be here presented became apparent.

The wheat-belt of eastern Washington is particularly well adapted to serve for a study of relation of total annual rainfall to crop growth. The soil over the entire belt is of uniform origin, the famous basaltic loam of the Palouse Country. This soil is remarkably uniform in its mineral composition. It varies somewhat in its percentage of humus, with the variations in annual rainfall, but these differences are not very marked, and the soil is unusually uniform in type for so large an area. The length of the growing season is practically the same over the entire area. The distribution of the rainfall throughout the year is practically identical everywhere in the wheat belt, there being the characteristic "rainy season" in the winter, and the "dry season" in the summer. The wheat crop very generally secures its moisture from the supply stored up in the soil from the winter season. Even the elevation above sea level is practically uniform, the wheat being generally grown on the upland plateau formed by the great basaltic overflow which is of the same general elevation. In short, the total rainfall for the year is practically the only variable among the factors which influence plant growth and composition. The region, therefore, serves admirably for the purposes of study of the relation of protein content of wheat to rainfall supply.

The analyses made during our five years' study included a total of 456 samples of wheat. Nineteen different varieties were represented, but the great majority of the samples were from the eight varieties most commonly grown, the remainder being represented by only a few scattering samples. The samples came from all the different wheat-growing sections of the state and were so selected as to secure a fairly uniform distribution over the entire wheat belt of the state.

In the following table (Table I) is shown the average moisture and protein content of all the samples of each of the leading varieties grown in the state, the varieties being arranged in the order of their average protein content.

TABLE I.—*Average Composition of Leading Varieties of Washington Wheats.*

| Variety. | No. of Samples. | Percent Moisture. | Percent Protein. |
|---|---|---|---|
| Durum (macaroni)........ | 13 | 9.58 | 12.86 |
| Bluestem..................... | 126 | 9.91 | 12.44 |
| Red Allen.................... | 17 | 11.05 | 12.04 |
| Jones's Winter Fife. ..... | 43 | 9.70 | 11.61 |
| Turkey Red................. | 55 | 9.43 | 11.27 |
| Little Club ................. | 65 | 10.08 | 10.75 |
| Fortyfold .................... | 27 | 10.04 | 10.74 |
| Red Russian............... | 16 | 9.85 | 9.76 |

The percentages of protein are not reduced to water-free basis, but the relation between the varieties would not be different if this were done.

It might be noted, in passing, that the spring-sown varieties are at the top of the list, while the winter varieties are invariably lower in protein. Little Club, a spring wheat, is an apparent exception, but this variety is very hardly and is very commonly seeded in the fall in Washington, more than half the samples of Club analyzed coming from fall-sown wheat.

The wheat-belt of Washington is divided by certain river valleys or other topographic features into certain fairly well defined districts. In Table II, the average composition of all the samples coming from each of these districts is presented.

TABLE II.—*Average Composition of Washington Wheats, Arranged by Districts where They were Grown.*

| District. | No. of Samples. | Percent Moisture. | Percent Protein. |
|---|---|---|---|
| S.E. Whitman Co..................... | 45 | 10.25 | 10.63 |
| N.E. Whitman Co..................... | 23 | 10.97 | 10.75 |
| S.W. Whitman Co..................... | 18 | 9.98 | 12.53 |
| N.W. Whitman Co..................... | 29 | 10.60 | 11.65 |
| Garfield and Asotin Cos..... ........ | 57 | 8.72 | 10.96 |
| Walla Walla Co........................ | 48 | 11.02 | 11.56 |
| Okanogan Co.... ........................ | 17 | 9.21 | 12.37 |
| Douglas Co.............................. | 41 | 10.59 | 12.25 |
| Lincoln Co............................... | 23 | 11.17 | 11.16 |
| Adams and Franklin Cos............ | 45 | 9.67 | 12.82 |
| Klickitat Co............ ............... | 10 | 8 97 | 9.03 |

The purpose in presenting these two tables is to show that while there are certain varietal differences of composition, the district or environmental variations are even greater. The samples being fairly well distributed over all the districts, and each district having samples of all the common varieties, the conclusion may be easily reached that environmental conditions are as important, if not a more potent influence, in determining chemical composition, as are varietal characters.

Immediately upon the completion of the tabulation from which the figures in Table II are taken, it appeared possible that the observed differences in protein content might be correlated with the rainfall in the various districts. The records of the Weather Bureau were consulted, and the total rainfall at a central point in each district, for the five years period during which the crops under investigation were grown, was ascertained. The resulting correlation is shown in Table III.

TABLE III.—*Relation of Protein Content to Rainfall.*

| District. | Percent Protein. | Weather Station. | Rainfall, 1905–9, in Inches. |
|---|---|---|---|
| Adams and Franklin Co. | 12.82 | Hatton | 45 |
| S.W. Whitman Co. | 12.53 | | |
| Okanogan Co. | 12.37 | Omak | 50 |
| Douglas Co. | 12.25 | Waterville | 58 |
| N.W. Whitman Co. | 11.65 | | |
| Walla Walla Co. | 11.56 | Eureka | 69 |
| Lincoln Co. | 11.16 | Wilbur | 73 |
| Garfield and Asotin Cos. | 10.96 | Pomeroy | 82 |
| N.E. Whitman Co. | 10.75 | Rosalia | 97 |
| S.E. Whitman Co. | 10.63 | Pullman | 103 |
| Klickitat Co. | 9.03 | Goldendale | 116 |

From these figures it is apparent that under conditions of uniform soil, growing season, distribution of annual rainfall, elevation, etc., with the total annual rainfall the only variable, the average protein content of wheat varies inversely with the total rainfall received.

Whether this relationship is of wider application cannot yet be definitely settled. Professor E. G. Montgomery, in an unpublished paper read before an agricultural society meeting in Nebraska, divided the wheat-growing districts of the United States into certain groups depending upon the degree of " softness " or " hardness " of wheat grown in them. I have taken the trouble to secure the records of rainfall at some typical central point in each of the districts as classified by Professor Montgomery, and in Table IV I have shown these figures, the districts being arranged in the order suggested by

Montgomery, the "soft" wheat sections at the top of the column with the degree of "hardness" increasing as we read downward. The Utah section should probably be omitted from the table as much of the wheat in Utah is grown with irrigation, and the annual rainfall, therefore, represents only a portion of the moisture available to the crop.

TABLE IV.—*Rainfall in the Principal Wheat Districts of the United States.*

| District. | Weather Station. | Duration of Record. Years. | Average Annual Rainfall. Inches. | Rainfall March to June Incl. Inches. |
|---|---|---|---|---|
| California | Sacramento, Cal. | 40 | 19.7 | 5.5 |
| Wash.—Ida.—Ore. | Walla Walla, Wash. | 45 | 18.6 | 5.8 |
| Utah (irrigated) | Logan, Utah | 13 | 13.4 | 6.4 |
| Southern coast | Baltimore, Md. | 30 | 45.0 | 15.8 |
| Central Miss. Valley | Dubuque, Ia. | 40 | 36.0 | 12.8 |
| Nebr. spring wheat | Hastings, Nebr. | 40 | 25.3 | 11.8 |
| Hard winter wheat | Dodge City, Kans. | 30 | 20.3 | 9.4 |
| Durum (macaroni) wheat | Pierre, So. Dak. | 35 | 16.8 | 8.7 |
| Hard spring wheat | Bismarck, N. Dak. | 29 | 17.7 | 9.0 |

I realize that the rainfall at the particular point selected may not accurately represent that of the entire district, but I assume that it is fairly safe to draw the following conclusions, namely, that if the wheats of the Pacific Coast States are taken into consideration in the comparison, there is no regular relation between the type of wheat and the total annual rainfall, or that received during the growing season; but that if we eliminate the Pacific Coast wheats from the comparison the order of rank of the wheats in the other several districts with respect to "hardness" is the same as the order of rainfall supply.

The unusual "softness" of Pacific Coast wheats is due, without doubt, to the cool harvest weather, inducing slow ripening in spite of the low moisture supply. There is ample evidence, both experimental and theoretical, to support the view that the relative protein content of the grain is determined chiefly, if not wholly, by the rapidity of ripening of the kernel after it is once formed.

# THE PURE-LINE METHOD OF BREEDING DROUGHT-RESISTANT WHEATS AND SIMILAR CEREALS.

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The pure-line method of breeding is known chiefly through the work of Dr. Hjalmar Nilsson, Director of the Swedish Agricultural Station at Svalof. Dr. Nilsson found that the so-called varieties of field crops with which he was working were not units in themselves but were made up of a comparatively large number of strains or elementary species. These were found to differ widely in economic value and in botanical characters, and when isolated to breed true to type. From the results of several years' work Dr. Nilsson concludes that improvement of field crops can be effected more easily and more rapidly by the isolation and determination of the value of the constituent strains than by the method of continuous selection formerly used.

The essential difference between the two methods involves both practical and theoretical considerations.

Continuous selection is based upon the assumption that every selection necessarily results in improvement, providing only that the right selection is made. In other words, it is assumed that selecting the best individuals each year from the progeny of the best of the preceding year will constantly and indefinitely result in improvement as long as the selection is continued.

The pure-line method, on the other hand, emphasizes the composite character of most varieties and insists upon the determination first of the value of the constituent strains. It does not deny the possibility of improving a pure strain but states that improvement is most likely to be achieved by the detection and propagation of favorable and permanent variations.

The pure-line method emphasizes the importance of determining the value of the constituent strains of a variety while continuous selection emphasizes the possibility of continuous improvement by selecting most favorable variations. The former places the emphasis upon the initial selection; the latter upon the following selections as well. Whichever method one adheres to theoretically, the former has certain advantages in our present state of progress in breeding drought-resistant cereals which should not be disregarded. The purpose of this paper is to show why this is true and to point out its application to this problem.

It is only a few years since attention was directed to the possibilities of growing crops in the drier sections of the United States. And it is only during a short period of time that experimental efforts have been directed toward determining the best crops to grow and their improvement. To properly understand the methods to be followed in the improvement of crops for these regions it is necessary to review briefly some of the results so far obtained.

The first step in the improvement of the crops of any section is the determination of the value of varieties already in existence. In the Northern Great Plains this work is well advanced for small grain crops. The United States Department of Agriculture and the State experiment stations have for several years been conducting tests of varieties obtained from all parts of the world. The data which have accumulated show, with a reasonable degree of certainty, the superiority of certain varieties. The following are worthy of special notice: Sixty-Day, Kherson, and Swedish Select oats; Kubanka durum wheat, Kharkov and Turkey winter wheats, obtained from Russia; and the Bearded Red Fife, a spring wheat of unknown origin.

The tests have been continued for such a time, the results agree so closely and the search for new promising varieties has been so thorough that it seems that further improvement of both wheat and oats, for this section as a whole, must be sought through selection from these varieties, rather than through the introduction of new varieties. That such improvement of these cereals is possible can scarcely be doubted from a knowledge of their composition.

With the exception of the Swedish Select oat, which is a pedigreed strain, or the product of a single plant, all the varieties mentioned are composed of a comparatively large number of different types. The Turkey and Kharkov winter wheats furnish a good example. These varieties are composed of a large number of types which may easily be distinguished, the number found depending upon the number of characters considered and the completeness of the study made of them. These types differ widely in botanical characters, and in such economic characters as color, hardness and quality of grain, and in height, resistance to winter killing, drought-resistance and yield. From three years' experience in growing them it seems that they remain true to type except when the result of an accidental cross. This being true, the chief problem in the improvement of these varieties is the isolation of the various strains and the determination of their relative values. This involves not only such considerations as relative yields and quality of grain, but also a study of the characteristics of each, especially in regard to their reaction to special or abnormal conditions.

The methods used in accomplishing this end vary in unessential details with different workers. That used at the Bellefourche Experiment Farm of the United States Department of Agriculture, located in western South Dakota, seems to meet the requirements. For the purpose of bringing out essential details a brief outline of the methods used will be given. The first step in the pure-line method is the isolation of individuals. In the work at Bellefourche this has been done by selecting single heads from the plat or field. After taking such notes as are desired the heads are thrashed and the seeds sown, those from each head in a row by themselves. The rows are usually about five feet long and eight inches apart. About twenty-five kernels per row are sown at uniform distances apart. At least every fifth row is a check row, sown to the parent or some standard variety. Plants instead of single heads have sometimes been selected when they could be easily separated from the adjacent plants. In such cases two or three heads from each are sown, each head by itself.

In making the selections an effort is made to obtain every type present in the variety. Special attention is directed toward obtaining the most promising types. For practical reasons it is advisable to make a number of selections of each type, since it is not always possible to distinguish clearly between types differing in economic value.

Selecting from the plat, or field, seems preferable to the method of first planting foundation beds. Planting foundation beds from which to make selections entails a very considerable amount of extra time and labor. The only advantage gained by so doing is a description of the original plant and the knowledge that it was grown under conditions similar to those of every other plant. Both considerations would seem to be of doubtful value until it is shown conclusively that the best plants grown under those conditions are usually the parents of improved strains.

This seems doubly true when one considers that with but little extra labor one can make head selections from the field or plat, plant them in rows, and make observations on the growth and behavior of the rows in the same season that would otherwise be required for making observations on the original plants. There is also in the former case a much larger number of plants from which to make selections.

There may be cases where it is advisable to plant foundation beds. Thus one may in special cases decide to begin the improvement of a certain variety as soon as it is introduced. In this case selections can not be made before a crop is produced. If one prefers, seed can be sown in a foundation bed without loss of time and without much additional labor.

As compared with the centgener method of planting, the row method is much simpler, easier, requires less help and less time, and, as far as can be seen, the results are fully as reliable.

As soon as sufficient seed is obtained, usually the second year, the selections are grown in rows 60 feet long. The seeding is done with a disk drill, the same as that used in seeding the field plats. Sufficient seed for a row is placed in every other cup of the drill, thus seeding the rows about 15 inches apart. In this way, when using a 10-disk drill, five rows are sown each time the plat is crossed. If there is sufficient seed the selections are sown in what may be termed multiple series. That is, the series of rows is repeated from two to ten, each in a different part of the field, the number depending upon the amount of seed and the time and space available for the work. With the equipment at the Bellefourche farm it has usually not been possible to grow more than three rows of each selection. Every fifth row is a check row, sown with the parent, or some standard variety, as in the head rows.

The chief advantages in growing the selections in the manner outlined are as follows: In both the head rows and the increase rows the selections are sown under probably as uniform conditions as can be obtained. The environment is similar to that of the field. Seeding with a drill insures uniform depth of seeding and uniform germination. It also insures uniform rate of seeding except as influenced by the size of the seed, which is a factor in field tests also. The check rows furnish a valuable index as to the uniformity of the soil and the amount of experimental error. Planting the rows in multiple series furnishes an additional index of the amount of experimental error, and tends to reduce it to a minimum. With a limited amount of help it is possible to grow a larger number of selections than by any other method of which I am aware.

A practice lately adopted, and apparently of some value, is that of sowing the selections in the order of their supposed excellence. That is, the selections are rated in regard to such points as yield, quality of grain, hardiness, and other points considered of value, and arranged accordingly. Those considered best are sown in the first rows, and the poorer ones last. The result is that there is before the operator at all times a sort of graphic representation of the performance of each selection, a consideration of some value when, for practical reasons, it becomes necessary to reduce the number of selections.

As soon as sufficient seed is obtained the best of the selections are increased by growing in fiftieth-acre plats. This size of plat has been selected because of convenience in seeding, one width of the drill seeding practically that area on our standard plats 8 rods long. As in the rows, at least every fifth plat is a check.

The question has arisen as to the advisability of continuing the work from this point by increasing to tenth-acre plats, as is usually done, or to continue growing the selections in fiftieth-acre plats but in multiple series.

It seems that a consideration of the amount of experimental error present in tests of this kind must convince any one of the necessity of more exact work than has been done in the past. The experimental error due to variation in the soil, and other causes, is often greater than the actual inherited difference between varieties and strains. The use of check plats, if sufficient in number, gives a fair indication of the experimental error, but does not eliminate it. It seems, moreover, that calculating the yields of the various plats to a uniform soil basis, as is sometimes done, presupposes a uniformity of variation that often does not exist.

Land and labor are probably the two factors which more than anything else limit the number and extent of field tests that may be conducted on an experimental farm. It is possible to grow five fiftieth-acre plats on the area required for one tenth-acre plat, sufficient allowance being made in each case for alleys. In other words, five plats each of the same number of strains can be grown in fiftieth-acre plats on the same area that is required for one tenth-acre plat. It is extremely difficult to show any decided difference, except in cost of operation, in favor of the larger plat. The advantage in favor of the five smaller plats in reducing the experimental error can scarcely be doubted.

Exact data concerning the comparative cost of growing five fiftieth-acre plats and one tenth-acre plat are not available. From some observations made by the writer in growing them, it seems that the increased cost in the former case would not exceed 25 percent for thrashing, and probably not more than 50 percent for harvesting. The difference in time, if any, required for seeding the smaller plats is slight.

The writer does not doubt that the greater accuracy would more than repay the extra cost.

### *Discussion by R. W. Thatcher.*

*Mr. Chairman:* I have been very much interested in the paper which has just been read. The breeding of cereals for special purposes has recently developed as a field of fascinating interest, as well as of immense practical importance.

It seems to me, however, that the time has come for workers in this field to go a little deeper into the theory of plant-breeding, as applied to cereal improvement, than we have yet done. We have discussed the comparative merits of different methods of selection, but have left untouched the more fundamental question as to whether it is possible to accomplish any change of type by any method of selection.

Professor Spillman, and perhaps others, has recently advanced the statement that it is not possible, by any mode of selection, to change the type of a close-fertilized plant; or, in other words, that in order to change the type there must be the introduction of new blood-lines, by hybridization with other varieties or other strains of the same variety. Cereals are, as a rule, self-fertilized or close-pollinated plants. There appears to me to be ample experimental evidence, however, that it is possible, by selection, to change to a considerable degree certain physical characters of these cereals, such as length of head, compactness of mesh, length of beard, or awn, etc., etc. But our own experience, at the Washington Experiment Station, after five years of careful line-selection for high- and low-nitrogen content, has been that we are just where we were at the beginning, and have not changed the type of the grain in the slightest degree. This seems to indicate that, in so far as chemical composition is concerned, it is impossible to change the type by selection alone. The question arises, then, whether chemical composition is a different kind of character than length of beard, or other physical characters.

This raises the whole field of inquiry as to whether certain characters may be fixed or changed by selection, while others may not; or whether there is yet some more fundamental principle in plant-breeding as applied to self-fertilized plants, which we have not yet taken into account.

# THE INHERITANCE AND EFFECT OF SUCKER PRODUCTION IN CORN.[1]

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About the time the experiment herein recorded was begun, and for some years previous, there was much talk among farmers and to some extent among experiment station agronomists, concerning the effects of suckers or tillers on corn, some holding that they were injurious and should be removed before they had made any considerable growth and some farmers were actually practicing "suckering," i. e. going through their corn fields and pulling off the suckers. It was also held that sucker production is a heritable characteristic and could and should be discouraged by selecting seed ears from only such stalks as did not produce suckers.

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To secure some specific data concerning these points, the Indiana Experiment Station, in the year 1906, undertook an experiment with two plats of corn, using the ear-to-row method of breeding. In one of the plats (plat 11) seed ears were continuously selected from detasseled individual ear-rows showing a low percentage of suckers and from stalks without suckers so far as reasonably good seed ears could be found, while on the other (plat 29) seed ears were continuously selected from detasseled ear-rows showing a high percentage of suckers and always from sucker-bearing stalks. The term "ear-row" is used in this paper to mean a row planted from an individual ear.

Plat 11 was begun in 1904 and in 1905 seed for plat 29 was selected out of this for planting in 1906. Both plats, therefore, originated from the same lot of seed ears. The variety used was Reid's Yellow Dent which had been secured a year or two previously from the Funk Bros. Seed Co., at Bloomington, Ill.

## Experimental Methods.

The method of seed preparation, planting and general field treatment was the same in both plats. The usual pedigree records were each year made of the dam seed-ears used and the sire seed-ears were selected and planted in the same way in both plats. In 1905, twenty-four individual ears were planted in plat 11 in alternate rows and these detasseled. From these all the seed for the 1906 planting in both plats 11 and 29 was selected. In 1906, forty individual ears were planted in plat 11 and twenty-four in plat 29. The sire seed in each case consisted of a number of selected ears shelled together and planted in the border and alternate tassel-rows. In plat 11, forty dam rows were planted from individual ears in 1907, forty in 1908, twenty-six in 1909, forty in 1910 and forty in 1911. In plat 29, sixteen dam ear-rows were planted in 1907, forty in 1908, forty in 1909, thirty-two in 1910 and forty in 1911. Each year the sire seed was selected and planted as in the first instance until 1909 after which the same number of hills in each sire row was planted from each of the sire ears used in order to secure the greatest possible uniformity in all sire rows, as these were used as checks in determining the relative productiveness of the dam ear-rows. In all cases the planting was done by hand, droping three kernels per hill, and all rows were later thinned to two stalks per hill.

Beginning with the year 1907, the system of planting followed was to plant the dam ears from a single family ten rows apart so as to distribute them as uniformly as possible throughout the plat. In determining the comparative yields of the dam ear-rows each was first compared with the average of its two flanking sire rows, after all had been corrected for stand to the average of the plat. Since all the sire rows were planted with a uniform number of kernels from each of the sire ears used, this system of checking was as perfect as could be secured. The plus or minus of each dam ear-row was then added to or subtracted from the average of all the sire rows and calculated to a bushels-per-acre basis. The yields thus shown were then as correctly comparable as could be expected, no matter in what part of the plat the particular rows compared were located. With this system of planting and checking it was interesting to note how uniformly superior or inferior the individual ear-rows of any particular family were in point of yield, sucker production and trueness to type when brought together on the record sheet, showing a marked degree of similar inheritance. It will be remembered that the individuals of any family were distributed ten rows apart in the plat and so their similarity could not be attributed to similarity of location. Each year the seed ears were selected from the highest yielding families of good type which at the same time showed the desired high or low sucker-producing tendency. Since the sire seed more or less uniformly affects the whole plat, the sire ears were always selected from the families showing the desired characters in the highest degree.

## *Results.*

In summing up the results of these experiments it is desirable to first consider the character of the seed ears used in each plat. In general, the type of ear selected in each case was the same, the best formed ears from the chosen rows being taken. The roughly dented type of ear was given the preference.

In Tables I and II are shown the average weight of the dam seed-ears, the weight of the seed-ears used in the rows from which dam and sire seed were selected, and the average percent of suckers in the rows from which the dam and sire seed was selected.

Plat 29 is the high sucker plat and plat 11 is the low sucker plat.

An examination of Table I shows that the seed ears used in plat 11 were slightly heavier than in plat 29, amounting to .37 of an ounce on the average. In the case of the grand-dam, the difference was also in favor of plat 11, amounting to .6 of an ounce on the average. It will be seen later that the differences in yield are not in accord with these differences in the weights of the seed ears as the yields are considerably in favor of plat 29. The latter may be largely explained, however, by the fact that plat 29 was located on richer soil in 1910 and seemed also to have more favorable conditions in 1911. (See yields, Table III.) With the exception of these two years, the differences in yield were not important.

Table I.—*Average Weight of Dam and Grand-dam Seed Ears.*

| Year. | Plat No. 29. | | | Plat No, 11. | | |
|---|---|---|---|---|---|---|
| | Average Weight of Dam Seed Ears, Ounces. | Average Weight of Seed Ears Planted in Rows from Which Seed Was Selected, Ounces. | | Average Weight of Dam Seed Ears, Ounces. | Average Weight of Seed Ears Planted in Rows from Which Seed Was Selected, Ounces. | |
| | | Dam Seed. | Sire Seed. | | Dam Seed. | Sire Seed. |
| 1906 | 14.37 | | | 13.07 | | |
| 1907 | 12.86 | 14.41 | 14.25 | 12.51 | 13.82 | 12.75 |
| 1908 | 12.68 | 13.70 | No record | 13.64 | 12.13 | 12.40 |
| 1909 | 9.53 | 12.40 | 12.76 | 10.54 | 13.44 | 14.10 |
| 1910 | 10.29 | 9.42 | 9.46 | 12.74 | 10.76 | 11.06 |
| 1911 | 13.03 | 11.27 | 10.67 | 11.56 | 12.30 | 13.22 |
| Average, | 12.12 | 12.24 | 11.77 | 12.34 | 12.49 | 12.71 |

In Table II, the differences in percent of suckers in the rows from which seed was selected are to be expected, of course, since the seed in plat 29 was purposely selected from rows showing a high percent of suckers. The yields of the rows from which seed was selected were, on the average, practically the same.

Table II.—*Average Percent of Suckers and Average Yield of the Rows from which Seed was Selected.*

| Year. | Plat No. 29. | | | | Plat No. 11. | | | |
|---|---|---|---|---|---|---|---|---|
| | Average Percent Suckers in Rows from Which Seed Was Selected. | | Average Yield of Rows from Which Seed Was Selected, Bu. per Acre. | | Average Percent Suckers in Rows from Which Seed Was Selected. | | Average Yield of Rows from Which Seed Was Selected, Bushels per Acre. | |
| | Dam Seed. | Sire Seed. | Dam Seed. | Sire Seed | Dam Seed. | Sire Seed. | Dam Seed. | Sire Seed. |
| 1906 | | | | | | | | |
| 1907 | 4.25 | 3.44 | 65.3 | 65.3 | 3.16 | 2.44 | 71.4 | 64.0 |
| 1908 | 31.00 | 36.20 | Lost | Lost | 16.33 | 27.89 | 90.5 | 88.1 |
| 1909 | 28.68 | 30.10 | 41.9 | 43.2 | 21.18 | 17.71 | 37.0 | 39.0 |
| 1910 | 25.72 | 20.93 | 66.7 | 70.4 | 9.10 | 5.73 | 67.4 | 67.2 |
| 1911 | 94.12 | 88.34 | 82.3 | 87.2 | 10.02 | 14.47 | 67.5 | 67.4 |
| Average, | 36.73 | 35.80 | 64.0 | 66.5 | 11.96 | 13.65 | 66.7 | 65.1 |

TABLE III.—*Average Percent of Suckers and Average Yields of Dam Rows.*

| Year. | Plat No. 29. | | Plat No. 11. | |
|---|---|---|---|---|
| | Average Percent Suckers. | Average Yield, Bus. per A. | Average Percent Suckers. | Average Yield, Bus. per A. |
| 1906 | 3.24 | 62.6 | 3.50 | 63.5 |
| 1907 | 31.52 | Lost | 18.78 | 88.1[1] |
| 1908 | 24.81 | 41.2 | 13.81 | 31.8 |
| 1909 | 18.64 | 66.5 | 9.30 | 64.6 |
| 1910 | 83.68 | 89.1 | 12.85 | 62.7 |
| 1911 | 103.74 | 60.3 | 13.04 | 40.7 |
| Average | 44.27 | 63.9 | 11.88 | 52.7 |

[1] Not included in average.

In Table III are shown the average percent of suckers and the average yields of the dam rows in both plats. The percent of suckers represents the proportion of the total number of suckers to the total number of stalks in each case, not the proportion of sucker-bearing stalks. As was to be expected, the percent of suckers ran very much higher in plat 29 than in plat 11 and shows that sucker production is a heritable character and may be raised or lowered by selection. The records show, also, that sucker production is much influenced by the character of the season during the early stages of growth and also by the fertility of the soil. It was observed, also, that soil and season may be more important influences than heredity. The low percent of suckers in 1909 may be explained by the fact that the seasonal conditions were unfavorable. When the fertility, moisture, and temperature conditions are favorable to rapid growth the production of suckers is very much increased. The relative proportion of suckers to yield has not been appreciably affected in plat 11, while in plat 29 the effect of selection for sucker production has become more and more marked, especially in the last two years. At the beginning of the experiment the proportion of suckers was practically the same in both plats, while at the end it was 1.62 percent per bushel of yield in plat 29 and 0.32 percent per bushel of yield in plat 11, or over five times as many suckers in plat 29 as in plat 11, in proportion to yield.

The differences in yield are, on the average, in favor of the high sucker plat, but the relation of yield to sucker production cannot be told since, in 1910 and apparently also in 1911, plat 29 was located on richer soil than was plat 11, which fact may account for all the difference in yield and, to some extent at least, for the extreme differences in the percent of suckers. In the earlier years, the soil conditions were practically the same, and the yields more nearly represent the relation of the two plats in natural productiveness. It was the impression of the writer and others connected with the experiment from year to year, however, that higher sucker production was not detrimental to yield and was even in its favor. It was observed, also, that quite often the best seed ears were to be found on stalks having suckers. Unfortunately, on account of the necessity of isolating the plats, it was not always possible to have the same soil conditions for both. In 1911, however, the two fields would ordinarily have been considered equal.

TABLE IV.—*Average Yields of Ten Rows with Highest and Ten Rows with Lowest Percent of Suckers.*

| Year. | Plat No. 29. | | | | Plat No. 11. | | | |
|---|---|---|---|---|---|---|---|---|
| | Ten Highest. | | Ten Lowest. | | Ten Highest. | | Ten Lowest. | |
| | Aver. Yield, Bu. per Acre. | Aver. Percent Suckers. | Aver. Yield, Bu. per Acre. | Aver. Percent Suckers. | Aver. Yield, Bu. per Acre. | Aver. Percent Suckers. | Aver. Yield, Bu. per Acre. | Aver. Percent Suckers. |
| 1906 | 64.5 | 6.0 | 61.6 | 0.72 | 61.1 | 6.17 | 66.8 | .71 |
| 1907 | Lost | Lost | Lost | Lost | 94.3 | 33.67 | 84.5 | 7.91 |
| 1908 | 40.3 | 38.37 | 39.1 | 11.45 | 36.7 | 28.73 | 26. | 3.27 |
| 1909 | 64.0 | 29.90 | 71.7 | 8.80 | 64.9 | 15.78 | 62.7 | 3.88 |
| 1910 | 83.5 | 108.79 | 76.8 | 58.30 | 63.4 | 21.48 | 59.7 | 6.90 |
| 1911 | 58.0 | 132.71 | 59.3 | 70.17 | 42.9 | 19.80 | 39.5 | 7.78 |
| Aver. | 62.1 | 77.42 | 61.7 | 37.18 | 60.6 | 20.94 | 56.6 | 5.08 |

An examination of Table IV shows that relatively high sucker production has not been detrimental to yield but, on the contrary, seems to have favored it. In both plats the average yield of the ten rows having the highest percent of suckers is higher than the average of the ten rows having the lowest percent of suckers. The view sometimes expressed, to the effect that a tendency to produce suckers indicates extra vigor in the plant, seems to be strengthened by the results shown in Table IV, and it appears fair to conclude that within reasonable limits, at least, the sucker-producing characteristic is not detrimental to yield. It is not plain, however, that the sucker-producing stalks would not have done better had the suckers been removed soon after appearing, thus turning to better account the extra vigor which the sucker producing tendency seems to carry with it. It is clear that sucker production requires plant food which might be diverted to the main stalk and result in the development of a better ear. To some extent the suckers in plat 29 developed small ears, which helped to swell the yield. In plat 11 this was not observed to any extent.

Table IV further shows that sucker production has been materially increased in plat 29, the averages closely approximating those shown in Table III.

### *Relative Yielding Power of the Progeny of the Two Plats.*

To determine the relative yielding power of the high- and low-sucker strains, yield tests were begun in 1910 and repeated in 1911. After selecting the seed ears for the breeding plat in each case, enough of the best obtainable seed was selected from each plat to plant several yield-test plants, which were located in different localities. In each case the two strains were planted side by side, thinned to the same stand as nearly as possible and tended in the ordinary way.

The results of the four most reliable tests in 1910 and of the three most reliable tests in 1911 are shown in the following table.

TABLE V.—*Average Yields of Progeny of Plats 11 and 29, Bushels per Acre.*

| Plat. | 1910. | | | | | 1911. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | Aver. | 1 | 2 | 3 | Aver. | Two Yr. Aver. |
| 11 | 55.2 | 92.7 | 72.0 | 65.6 | 71.4 | 47.4 | 42.0 | 74.0 | 54.5 | 62.9 |
| 29 | 55.5 | 93.3 | 68.7 | 54.1 | 67.9 | 51 6 | 38.0 | 90.7 | 60.1 | 64.0 |

The results of the yield tests of the two plats shown in Table V are in favor of plat 29 by 1.1 bushels per acre. If, however, we leave out of consideration test No. 4 in 1910 and test No. 3 in 1911, which seem to show improbable differences, the two-year average becomes 59.0 for plat 11 and 58.8 for plat 29. In either case the difference is so slight that a definite conclusion as to the relative yielding power of the two strains cannot be drawn at this time, unless it be that there is practically no difference.

### *Summary and Conclusions.*

In summing up the results of this experiment it may be said:

1. Sucker production has been materially increased by selecting seed from sucker-producing stalks, thus showing that sucker production is a transmissible character.

2. The results of selection for sucker production are cumulative, since the proportion of suckers steadily increased as the experiment progressed.

3. The relative yielding power of corn does not seem to be

materially affected by the presence of suckers, as is shown by the yield tests.

4. In the earlier years of the experiment the evidence goes to show that a limited increase in sucker production may be favorable to larger yields of ear corn.

5. The extensive development of suckers with no reduction in the yield of ear corn, as shown in this experiment, seems to indicate that the sucker-producing character carries with it, or is conditioned upon greater vigor in the individual.

# THE INFLUENCE OF THE SOIL TYPE ON THE PLANT VARIETY.[1]

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## I. The Plant Environment.

Environment of any plant is composed of but two elements, namely: *climate,* or the combined effort of light, heat, air, moisture, etc., into which the stalk rises and the leaf spreads; and *soil,* or the *medium* into which the plant sends its roots in quest of food and drink.

### *Soil Type.*

In general, what the farmer terms "a kind of land" is technically known as a type of soil, possessing distinct characteristics as regards crop production. The soil type has, as a whole, definite texture, structure, color, origin, depth of soil and subsoil, topographic and drainage features, organic and mineral composition, native vegetation, and natural productiveness. It may be said that any factor which materially influences crop production on a given soil type in a given locality may be considered an element serving to differentiate between the given soil type and another in a distant locality, otherwise identical with the first, but not influenced by the same factor in the same degree.

The number of distinct soil types that have been recognized in different parts of the country is very great. Variations in any of the above characteristics may necessitate the establishment of recognition of a new type. For example, allowing texture, which deals with the size of the soil particles, to remain unchanged, variations in one or more of the other characteristics have enabled the U. S. Bureau of Soils to name over fifty types of clay soils; upwards of sixty different silt loam soils; more than 144 sandy loam soils, etc., each type differing from the others in some one or more essential qualities.

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[1] Submitted for publication December 14, 1911.

Every farm has one or more types of soil on it. Most farmers recognize this and, in general, soils are differentiated into types according as the best farmers perceive them to have different crop values. On close examination, however, most farms will reveal more types than their owners have suspected to exist. The U. S. Bureau of Soils has recognized and mapped upwards of 400 types of soil in the United States and the number goes on increasing as the subjects of soil classification and crop adaptation are studied more and more carefully.

### *Adaptation to Environment.*

Much has been done in this and other countries to discover the environmental conditions of both plant and animal life best suited to the fullest interaction of all parts of the organism.

The environmental conditions of plant life have generally been defined as climatic, geographical and physiographical location and conditions of food supply.

Climate has hitherto been stressed more than any other factor in plant production. And while no one will assert that climate is not the controlling factor in the latitudinal and altitudinal distribution of plants, yet, in the same latitude, where climate is uniform, except over small areas of different elevation, this factor cannot be said to account for the wide differences observed in the character and development of the different varieties of the same species of plant. While we would not care to minimize the very important place occupied by climate in the production of crops, still, *since this factor has been so generally emphasized* by leading scientists and experimenters in the field of agriculture, we may be excused for calling attention *more particularly* in this paper to the influence exerted by the type of soil in which the plant is forced to grow. The soil has, indeed, always received a passing consideration as a factor associated with the food supply of plants, but we hope to show in the following pages that the soil, or soil type, plays a vastly more important part in plant production than has hitherto been accorded it.

### *Adaptations Generally Recognized.*

When the plant is confined in a new environment it either dies or so readjusts its physical structure as to become gradually adapted to the new conditions surrounding it. The plant organism responds to every touch of environment.

There are certain broad adaptations of plants to soil environments that are recognized by every man possessed of a fair knowledge of agronomy. In the great wheat and corn sections of the central west a heavy clayey loam, occurring in what is technically known as the Miami series of soil, is admitted to be best suited to the former, while a silty loam, belonging to the Marshall series, is best adapted to the latter cereal. For early truck any experienced gardener will select a light sandy soil for out door culture. Every experienced grower knows that the alfalfa plant, regardless of climate, requires a large percentage of lime in the soil—a calcareous soil—to make its best yield.

Not only do the above named conspicuous and rather well defined adaptations of plants to peculiar soil environments exist, but on close examination we shall find that plants have adapted themselves to every physical environment in which it is possible for them to exist, or, as Bailey has put it, "Every Physical Environment Produces Adaptive Changes in Plants."

This theory of adaptation of the plant to the environment has engaged the serious thought not only of leading agriculturists but of leading biologists as well, and the only defense of this paper is that too little attention has been given the part played by the soil type *per se* in the many conserved adaptations. This thought could hardly have been more strongly or fittingly expressed than by Hilgard when he said "Under given climatic conditions every distinct type bears a characteristic vegetation." He further states that the natural vegetation of any area represents the best adaptation of plants to soils in the results of the long period of the struggle for existence between competing species. In other words, under given climatic conditions, the species make the best development that are best adapted to the soil in which they grow.

Scientists have recently concluded some experiments and made some discoveries that throw great light on the subject under discussion and go far in the confirmation of what they have believed to be true for over a half a century, but have hitherto lacked experimental data sufficient to justify them in drawing general conclusions.

Much of our most valuable information on this subject has come from our own and foreign agricultural experiment stations, and no small part from various botanical laboratories. These scientists have arrived at extremely interesting conclusions relative to the adaptation of plants to soil environments but have been put at great disadvantage in being unable to make practical use of many of their discoveries. To illustrate; the discoverer may say his variety does best on a clay soil. We pointed above that we have already found over fifty types of clay soil. To which one of these is his variety adapted? He may say his variety makes its best development on a sandy loam soil, but we have about a hundred and fifty different types of sandy loam soil. To which one of these is his variety adapted? Most frequently we find the new variety best suited to a loam, but we have seventy-five or more distinct loams. You thus see that the amount of good the agricultural scientist, especially the agronomist, can confer on the public bears a direct ratio to the amount of his knowledge of the location, extent, and general characteristics of the type of soil with which he is dealing.

His discovery is of interest only to science and has nothing of value to the practical plant grower. Not only so but the scientists are likely to get hold of his plant novelties and scatter them all over the country, thus doing an injustice to the man who desires help.

Returning briefly to the work of our experiment stations, and others, the Kansas experiment station found two native grown varieties of corn (not the highly selected seed) to be often more hardy, better producers, and better adapted to the soil of the station (Oswego silt loam) than even the best and purest improved varieties. In this experiment the director of the station concludes "There is no question but that there is a great difference in varieties of corn in their adaptation to different soils and climates."

In its experiments with oats this station concludes: "The strain of red Texas oats which has given the largest yield for the last two seasons, '05–'06, has been grown at the station for four years and has seemed to improve rather than deteriorate in quality and yield." This shows some of the possibilities of a plant that has perfect correspondence with its environment or is perfectly adapted to the soil and climate in which it grows.

The Indiana experiment station finds after testing a number of varieties of wheat that "standard varieties have maintained their yield and quality on the same soil for fifteen years and most of the new varieties have, as a rule, failed to do so well as the standard varieties which have long been grown here."

In his admirable work at the Minnesota station, Professor Hays found that it was best to obtain beets adapted to the various local conditions and that the seed could best be bred under conditions similar to those where the crops were to be grown. That Mr. Hays appreciated the influence of soil type on the plant is shown in his statement that "special varieties are needed in many localities where peculiar soils exist." Speaking with particular reference to Minnesota he was convinced that Minnesota alone needs needs numerous varieties of corn bred for its various types of soil.

Perhaps we could quote no greater modern authority on this subject than Prof. Hugo De Vries who states that local variations in soil (and this is known only too well by all practical beet growers) will directly affect the percentage of sugar in beets, and that the variety of beet, etc., must be developed on the same kind of soil as that on which it is to be grown. He says further that this principle has been tested and found reliable and has supplanted almost all others at the Svalof experiment stations, Sweden. Professor De Vries thinks also that "all trouble incident to imperfect adaptation to soil can be avoided by the farmer only by selecting his own seed on his own land." From our point of view this statement is certainly true but any one conversant with the amount of knowledge, time, and tediousness required in developing a good and distinct variety anywhere will see how impossible this remedy is of general application. The development of varieties of plants for distinct soil types is a state or national problem and scarcely can be accomplished without the aid of one or both of these bodies.

The U. S. Department of Agriculture has collected a great many interesting and valuable data on this subject. It has studied plant growth and adaptability almost all over the known world, yet, from our point of view, nothing of more far reaching importance has been brought to the notice of the American people than that expressed by Mr. A. D. Shamel when he said "The farmers suffer great annual loss from the growing of varieties not adapted to the soils of each region where the crops are grown."

"The range of adaptability of varieties has never been determined so that, with known soil, growers can intelligently buy seed for planting; however, with more knowledge of the relation of the different types of soil to the different varieties of crops it will be possible for the breeders to produce and distribute seed especially adapted to particular sections."

### *Influence of Soil Type on Development of Plant Variety.*

It is a fact of utmost importance to agriculture that plants can be, and are, greatly modified by the environment in which they are placed.

It has long been known that the different varieties of our staple crops make better yields, both of quality and quantity, when grown on certain soils than when grown on others. Until recently, however, our soils had not been differentiated into series and types, consequently, no law of general application could be deduced from the many observed facts.

Inasmuch as each environment produces adaptive changes in plants, it follows that widely different environments will produce marked variations in the same variety of plants.

If we take a particular variety of any plant, as cotton, and grow it in widely different soil environments (climate remaining the same) certain adaptive changes will appear, enabling the plant to correspond more completely with the various new conditions. Now, if by careful and persistent selections the grower each year weeds out all plants but those most nearly corresponding to the new environment, he will soon find these adaptive variations to have become so intensified and his plants to have undergone such a pronounced physiological change that he can legitimately say a new variety of cotton has appeared in his field. If, for example, we take a variety of cotton having a small stem, leaf and boll, grown for generations on the Norfolk sand and transplant it to the Yazoo loam, we will have changed the environment of the plant by changing the soil type. We will have increased the food and moisture supply of the plant enormously. In order to utilize the increased supply of feed and drink the plant begins to gradually enlarge its stem, leaf and boll. Not all the plants in the field will show a pronounced adaptive change at once, but here and there will be found a plant with an abnormal development. The enlarged boll may appeal to the grower as a desirable characteristic, and he may, therefore, select for seed only those plants that have the extra large boll. The following year he will plant these selected seed in the same soil environment and again select seed only from the plants having the enlarged stem, leaf and boll. This practise of selection and adaptation is continued till every plant in the field closely corresponds to the ideal set by the grower, and, perhaps, without intending to do so, he has produced a new variety of cotton, thoroughly adapted to the new soil environment.

After the big boll variety of cotton has been grown for a number of years on this rich bottom land soil, we will suppose the grower takes the seed and plants them on the upland soil again. He will have again changed the environment by changing the soil type. The available food and moisture supply will have been greatly decreased, but the desire of the plant for a large supply of these will not have been diminished. It is thus subjected to a process of starvation, which causes it gradually to decrease the size of stem, leaf and boll in order to continue its existence under the changed conditions of life. Early maturity or some other characteristic of upland plants growing under restricted food supply may suit the grower's fancy in some of the plants, and these he will select for planting the following year. Should he continue this practice of selecting and adapting the plants to a particular type of upland soil for a number of years, he will finally have developed a variety of cotton having a small stem, leaf and boll, peculiarly adapted to the upland soil, as was the other in the case of the bottom land soil. It is thus possible to take a variety of plant and, by changing the soil environment, induce a radical change in its characteristics, even to the extent of creating a new variety.

Some twenty years ago Director Tracy, of the Mississippi Experiment Station, found that "many varieties of cotton which will produce a strong, long, silky fiber when planted on rich river bottom soil soon lose their superior qualities when grown on the drier hill lands," and that "the percentage of lint also varies with the soil on which it is grown." He also found "where samples of the same variety have been accurately measured the lint varied greatly in length owing to differences in soil." Mr. Tracy found further that "some varieties gave enormous yields when all conditions were favorable, but failed miserably when planted on unfavorable soils." After a long series of careful investigations in citrus fruit-growing in the Gulf states, Prof. P. H. Rolfs concludes: "In the production of oranges it is absolutely necessary to choose the particular variety which is adapted to any peculiar soil."

Relative to the production of wheat in Tennessee, Director A. M. Soule, of the Tennessee experiment station, after testing a number of varieties, concludes: "The selection at random of varieties of wheat has led the farmers to conclude that the soil and climatic conditions prevailing in Tennessee are antagonistic to the production of a superior grade of wheat, but careful research has revealed the fact that when the varieties are found specially adapted to the soils in this state, the results are quite as satisfactory as those secured in other parts of the United States."

During our study of the adaptation of varieties of plants to soil types we have found in every case investigated that each variety has been developed in a quite distinct type of soil, and our study of the later history of these varieties goes to show that they give best results only when grown on soils similar to those on which they have been developed. *Indeed, it appears to us highly improbable that a good and distinct variety of any of our staple crops can be developed in a field where there is a medley of soil types. Uniformity of soil is essential to the production of a uniform variety of plant.* The Toole variety of cotton was developed on the Norfolk sand, and may be expected to give better results on this and closely allied types of soil than any other variety of cotton. The converse of the above proposition may also be expected to be found true, namely, that the Toole variety of cotton will give best results only when grown on the Norfolk sand or closely allied types of soil.

It is hardly too much to say that the farmers of this country lose millions of dollars yearly by not knowing the particular varieties of corn, wheat, cotton, etc., best suited to the different soil types found on their farms.

### *Seed Selection.*

There is, perhaps, no more potent factor in the adaptation of varieties of plants to soil types or soil environments than that of careful seed selection. As said above, when a plant is forced to grow in a new environment it at once begins to adjust itself to the new conditions of life. In case of the cotton plant, for example, we will see here and there in the field, during the first or second generation, a few plants making a better growth and setting fruit more liberally than the general run of the field. The grower will mark these plants and select seed from them for planting the following year, etc., and in a little while will have his whole field set with plants that are rapidly adjusting themselves to the new soil conditions. This practise of selecting seed from the best plants and planting these selected seed again on the same type of soil is the best—the only—means by which to force the plant to its highest point of productiveness. Indeed, seed selection is beneficial mainly in that it accelerates the complete adaptation of the plant to the particular soil environment.

### *Cumulative Effect of Seed Selection and Adaptation.*

It is generally true that any variety of plant will sport or change, even though it be kept on the soil to which it is specially adapted, but the variations in this case are generally in the desired direction.

The Minnesota Experiment Station, after many careful experiments to determine the effect of growing the same kind of plant in the same kind of soil (not in the same field, however) for a number of years in succession concludes: " The old idea that seed tended to run out when grown too long on the same soil is false." At the Nebraska Experiment Station a new variety of wheat was introduced some years ago and grown for several generations on the same type of soil (the Marshall silt loam). As the variety adapted itself to the new soil environment the yields increased. The seed was carefully graded each year and the variety showed a tendency toward continual improvement. Mr. W. W. Toole, the originator of the Toole variety of cotton, has for years been improving his cotton along the lines of early maturity and increased proportion of lint to seed. He now has not only one of the earliest maturing varieties, but one in which he has increased the percent of lint from 38 to 44. He tells me, moreover, that within a short time he expects to put on the market an extra early variety, yielding 46 percent lint, and that within ten years he will produce a cotton yielding as high as 50 percent lint.

We thus see that when careful seed selection is combined with uniform soil conditions, the variations of the plant are cumulative in the desired direction.

## II. Change of Soil Environment.

" If the environment remains the same," says Lamarck, " the species also remains the same." Spencer had in mind practically the same idea when he said " If the environment remains unchanged for many generations the plants become thoroughly fitted into the conditions and then remain in a state of equilibrium." You will recall that the variety was, in Darwin's time, pretty generally considered an incipient species.

From the foregoing definition of plant environment it is evident that a change in either soil or climate will produce a change in the environment.

Suppose we take as a simple illustration some of our potted plants that appear so beautiful along the thirty-second parallel and move them fifteen degrees north, leaving them unprotected. The change of climate alone kills the plant. Now take a plant that has been grown for a generation in a rich, moist loam, and repot it, using in place of the rich loam a rather poor sandy soil. With no change of climate the plant dies. Of course every one knows that with an extreme change of both soil and climate the plant must die, but how many scientific agriculturists have noted that with a change of soil type, it may be but a few yards away, the cultivated plant may not only have its form and habit of growth changed, but its yield so reduced as to place it far below the point of profitable production? We could bring forward more illustrations to substantiate this proposition than the limits of this paper will justify. We will quote, therefore, only a few of the leading authorities who have either conducted experiments or have observed in this field of thought.

While Mr. Hilgard was in Mississippi he noted that "A single variety of cotton, planted on two adjoining soil types, was so changed by the two soils as not to be recognizable as the same variety in the two fields." This observation has not only been made in the case of cotton but also in the growth of corn, oats, wheat, beets, etc. This breaking up of corn in habit of growth has, as a rule, been accompanied by reduced productivity.

Most experiment stations have demonstrated this conclusively. Kansas station has found that "the purest bred corn secured from other states, when grown under new conditions of soil . . . varies greatly in the type and quality of the corn produced, and must be carefully bred and selected again when planted in Kansas in order to secure a hardy and productive type of corn which is adapted for growing in the new environment." This bit of experimental knowledge is in perfect accord with Darwin's observation that "when plants are removed from their natural conditions they are extremely liable to have their reproductive systems seriously affected," and that "organic beings, long habituated to certain uniform conditions in a state of nature, when subjected to a considerable change in their conditions, very frequently are rendered more or less sterile." The works and observations of Messrs. Bailey and Webber have enabled them to voice practically the same opinion as that advanced by Darwin.

Contrary to popular opinion, Mr. A. M. Soule, of the Virginia Experiment Station, found that corn developed on thin land will not yield well when first grown on rich ground, and that, while western varieties will outyield our home-grown strains when put on soils made comparable to those found in the west, they will not yield as much on the thin lands of the east as the home-grown varieties.

The Illinois station found that many varieties of wheat, profitable when grown elsewhere, were worthless when grown on the Marion silt loam in southern Illinois, and that the Turkey red wheat, the best wheat for the Marshall silt loam at the station was out of its element when grown on the Marion silt loam in southern Illinois.

Returning again to plants as we see them in nature, who has not noted that certain varieties of plants are radically changed when their seeds fall on a distinct soil type, though the seed may not have fallen ten feet from the parent plant. Mr. Hilgard states that the black prairie belt in Mississippi, composed of a heavy black limy clay, produces a stout, vigorous species of post and black-jack oak, but when the seeds of these trees are placed on the non-calcareous clay soil of the flat woods country, they are so changed in form, habit of growth, and size that the inhabitants believe them to be a different species. Mr. Hilgard makes another interesting observation. The upland cypress has a characteristic cone shape while the lowland cypress has an umbrella-shaped top. But, says Mr. Hilgard, when seed of the upland variety falls on the swampy land it produces the lowland variety of cypress. This observation might have been doubted had it not come from so eminent an authority as Mr. Hilgard.

The above interesting data are hardly more remarkable than some given by Mr. De Vries. He found that two alpine varieties of milfoil, so nearly alike in botanical marks that many would think them the same, made quite different demand on the chemical constituents of the soil. The one was adapted to a silicious soil, the other to a calcareous soil. When both were placed on the calcareous soil only the one adapted to or developed on this soil, could survive; the other was crowded out. Bateson also found that "The common dandelion (*Taraxacum densleonis*) has in a dry soil leaves which are much more irregular and incised, while they are hardly dentate in marshy stations where it is called *Taraxacum palustre*." Both Darwin and Lamarck believe that not only the great amount of variation observed among our domesticated plants, but the great differences seen between the present plants and their prototypes, is due to the new environments to which they have been subjected, but the amount of variation due to the soil half of the environment never came up for much consideration.

Any practical alfalfa grower knows that alfalfa is very choice in its soil requirements, demanding a rich, heavy loam heavily charged with lime carbonate in order to make its best development and that when placed on a soil lacking in these essential qualities it makes a miserable failure. Apropos of this subject the Minnesota Experiment Station observed "Buying seed every few years from regions having different soils is unwise." Hon. H. D. Clayton of Eufaula, Ala., tells me that the Strickland big boll cotton, grown in connection with the Toole variety on land very similar to that on which the Toole has been developed fell far short of yielding as much cotton per acre as the Toole. The Strickland big boll was developed on the Waverly silt loam, the Toole on the Norfolk sand.

It is a matter of common knowledge that the Norfolk sand produces a very high grade of cigar wrapper tobacco, but when this variety of tobacco is grown on the Orangeburg clay it loses its superior qualities.

Not only have the experiment stations ascertained that definite varieties require definite soils but many practical farmers who have taken the trouble to keep careful notes tell me of similar experiences. I have known two varieties of cotton grown in the same field in which the soil was all alike, one to outyield the other a thousand pounds of seed cotton per acre, and that with identical cultivation and fertilization. The same is true to a greater or less degree with corn, wheat, and oats and, indeed, with all other plats whose actions in changed soil environments it has been my privilege to study. It is common among farmers to hear some man say the Early Rose potato gives him best results while his neighbor, just across the road, may say the Early Rose is all but worthless on his land. I have never found a case of such complexity of opinion where an examination did not reveal two distinct soil types. A characteristic case of changed environment comes to mind. A few years ago two brothers who had been making a splendid success growing potatoes on the high priced Wabash silt loam soil of the Kaw Valley, Kansas, heard of cheap land in Texas and made a purchase of several hundred acres of the soil known as the Orangeburg sand at Rockdale, Texas. The natives of that section volunteered to advise these brothers against such an attempt, saying they had never been able to grow any variety of potato on that "kind of land." But the advice was not heeded. The brothers brought their whole equipage with them from the Kaw Valley and proceeded to plant their crop of potatoes. They placed in the bank at Rockdale $5,000 with which to pay expenses. When the crop was harvested their books showed a loss of $3,000 with $2,000 of the original $5,000 in the bank. This they speedily drew out and returned to Kaw Valley. There is, so far as I know, no variety of potato well adapted to the Orangeburg sand though one might easily be developed. In this case there was a change of both soil and climate but a change of either one would have produced the same result. The brothers gave but $10 an acre for their land but it sells now, I am told, at about $30 an acre, for peach culture to which it is well suited.

In his paper on the "Modification of Cereal Crops by Change of Environment," Prof. T. L. Lyon says "It is desirable to breed a strain of any cereal under, as nearly as possible, the conditions under which it is to be grown. The more strongly bred a strain is the longer it will retain its quality under the new environment. The better suited it is for one set of conditions the more difficult it will be to adapt it to those that are radically different."

### *Readjustment to New Environments.*

Since plant organisms are so profoundly influenced by every touch of environmental condition, it follows that when they are changed from one environment to another they must, of necessity, undergo a corresponding change in their physical characteristics; and this change must be more or less pronounced according as the change of environment is great or small. If the variety of plant has been thoroughly fixed by years of selection and adaptation to the previous environment, the first, and may be the second, generation of plants may be expected to show a tendency to reproduce the qualities of the old strain, but since environmental conditions of life are always exerting a greater influence on the plant organism than its inherent qualities, the plant soon changes its habit of growth, etc., to fit the new conditions. It is during this period of readjustment that the plant is liable to become unprofitable to the grower. One example must suffice to illustrate. The Harvest King variety of wheat, adapted to the Marion silt loam of southern Illinois by a number of selections, beat a variety of the same name from Indiana three and nine tenths bushels per acre, and a variety of the same name from Michigan four and eight tenths bushels per acre. After three years, however, the foreign variety yielded as much as the home-grown Harvest King. This experiment showed not only a loss during these three years but no gain over the home-grown variety after the complete readjustment. We have a large number of similar illustrations where the differences in yield are very large, but since the limits of this paper will not admit their introduction they will occur in another paper on this subject. It is here, also, that the farmer is deceived; because of his new variety having done well last year he has faith in its future action, but the yields generally get lower and lower. Moreover, few farmers will keep a poor variety on their farms until it becomes thoroughly adapted to the new conditions, or, in other words, till their soils develop varieties adapted to them. If we take the cabbage plant for example, which in its domesticated state is adapted to a rich, moist, loam soil, and grow it on a poor, dry, sandy soil, it will, as Darwin puts it, "revert to a large extent, or even wholly, to the aboriginal stock, due largely to the definite action of the soil."

The Strickland big boll cotton is especially adapted to a rich, moist bottom land soil, the Waverly silt loam; the Toole variety to a rather poor, well drained upland soil, the Norfolk sand. When either of these varieties is grown in the soil environment particularly adapted to the other, the yield is materially decreased thereby. If we take the Drake cluster cotton, which has been kept pure for twenty-five years on the Houston clay, and grow it on rich, moist, bottom land soil it at once "goes to weed" and yields comparatively little fruit. The Minnesota Experiment Station has found that varieties of grain adapt themselves to local condition, and "varieties from seed brought from a distance must usually become acclimated before they can do their best." But when the readjustment to the new environment is complete and the plant begins to produce good yields, close examination will reveal quite a different variety from the one originally planted, as we said above. To illustrate, the Strickland big boll cotton was the result of the complete readjustment of the Bohemian big boll from the black, waxy land of Texas to the Waverly silt loam in Alabama. The result is a much smaller boll. It takes over sixty bolls of the Strickland to make a pound of seed cotton, while forty-six to forty-eight of the Bohemian are quite sufficient. Many other instances that have come under our personal observation might be given to show that varieties of plants transferred from one soil type to another to which they were not adapted have so decreased in yield as to make their continued cultivation unprofitable and have been discarded after the first season.

The present practice of our farmers is to purchase a new variety of plant, as cotton, corn, or wheat, wholly on catalogue descriptions or the advice of some friend and without regard or information as to the type or character of the soil on which the plants have been developed. The originators of these new varieties never think to say anything about the soils on which they were grown, never, perhaps, suspecting that the soil type could influence the future tendencies of the plant. These different varieties are thus taken out of their original soil environments, subjected to a continual round of readjustments to new conditions, and as a result, our crop yields are kept permanently below a reasonable average by reason of the adverse circumstances in which the plants are forced to grow.

## *Summary and Conclusion.*

In this paper we have found: (1) That with given climatic conditions the plant, sooner or later, becomes adapted to the soil type on which it is placed. (2) When the variety is removed to a radically different soil type, the new soil type and the plant variety react on each other in such a way as to break up the original characteristics of the variety and gradually develop a variety better suited to the conditions. This we called readjustment to the new environments and tried to show that during this period the productivity of the variety is likely to fall far below the point of profitable production. (3) We have tried to show also that the remedy recommended by some that each farmer should become a plant breeder and breed varieties for each of his soil types will almost surely prove impracticable since the great majority of them would require to be taught both the characteristics of a distinct variety and what constitutes a distinct type of soil. This, we feel, is a state and national problem. When a state has a large number of soil maps it is ready for the soil expert and the plant breeder to go to work. Otherwise, the national government should not be slow to launch out into this new field of agricultural research. (4) We have found also that the most important result of systematic seed selection is in accelerating the complete adaptation of the given variety to the given soil type. (5) A radical change produces a change in the characteristics of the variety and generally greatly reduces the yield of the plant. (6) When seed selection and adaptation are carefully combined we find the results to be cumulative in the desired direction.

We conclude, therefore, that, from an economic point of view, it pays best to grow our staple crops only on soils to which they are adapted or on soils similar to, or identical with, those on which they have been developed.

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## A PRELIMINARY REPORT ON A FIELD STUDY OF SOIL MOISTURE.

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As early as 1870 Lawes and Gilbert[1] isolated blocks of soil in their natural field condition, for the purpose of determining the proportion of rainfall which passed through known depths of soil during each season. For this work, blocks of undisturbed field soil 6 feet wide by 7 feet 3 inches long, and 20, 40 and 60 inches deep, respectively, were enclosed on four sides by a brick wall laid up in cement mortar and supported by means of perforated cast iron plates carried on transverse iron girders. The percolating water was collected by means of a large zinc funnel suspended below the perforated bottom.

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[1] Lawes, J. B., and Gilbert, J. H. On the amount and composition of the rain and drainage waters collected at Rothamsted. Rothamsted Memoirs 5: 1–31. Figs. 1–2.

Two decades later King[2] of Wisconsin made a study of the rise of water in natural field soil. In this work the blocks of soil were not isolated. A small area of soil kept entirely free from vegetation was kept covered to exclude rain and sunshine but so as to permit the free circulation of air over the surface. The water content of the soil was determined to the depth of 5 feet on May 14 and to the depth of 7 feet on July 17 and September 30 of the same year. At the conclusion of his report King makes the following observation: "The evidence from this experiment goes to show that subsoils 6 to 7 feet below the surface may contribute large amounts of water for the use of crops growing at the surface."

Some years later, in his work for the Bureau of Soils, King[3] isolated blocks of soil for the purpose of studying the rates of evaporation from soils under field conditions. In this work the blocks of soil were cut off from the adjacent soil of the field by digging trenches around them to a depth of 4 feet and encasing the blocks in a framework of lath so as to shut them off from a supply of moisture through the lateral capillary movement. One block in each set was cut off from a supply of capillary moisture from below by a similar provision. After encasing the blocks the soil was returned to the trenches and corn was planted on the blocks. No attempt was made to make these casings water tight and some difficulty was experienced from the rise of ground water from below into the blocks of soil. Rainfall was excluded by means of a tent carried by a single pole of gas pipe set on the north side of the hill of corn. During pleasant weather the tent was furled closely to the tent pole, but during rainy days the tent was unfurled and staked so that its margin came within 6 inches of the ground and completely excluded all rain. The idea in this experiment was to secure one set of cubes 4 feet on a side, where the soil was left in its natural, undisturbed condition and which contained a natural amount of moisture of the field at the time of the beginning of the experiment but from which all supplies of moisture from the sides and from the bottom were cut off, and a second set of cubes in which the supplies of moisture from the sides were cut off but free opportunity left for a rise of capillary moisture from below. A comparison of the two sets of cubes covering the soil types indicates that the cutting off of the capillary supply from below 4 feet resulted in a deficiency of moisture at the close of the growing season. The plants growing on these blocks of soil came to maturity, but were small, and most of them did not produce any ears. The conclusion drawn was to the effect that the moisture conditions came to be so prejudicial to growth that in no case was the development of the plants even approximately normal.

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[2] King, F. H. Investigations relating to soil moisture. Wisconsin Sta. Rpt. 1891, 104–105.

[3] King, F. H. Investigations in soil management. U. S. Department of Agriculture, Bur. Soils, Bul. 26: 198–205. 1905.

In 1904 Briggs and McCall[4] designed an apparatus for the study of moisture in field soils. The apparatus consisted of a Pasteur-Chamberland filter tube in the soil, connected by a short lead pipe to an exhausted two-liter bottle. Preparatory to placing the filter tube in the soil a core of soil was removed by means of a sampling tube, the external diameter of which was equal to the external diameter of the smaller end of the porcelain tube. The filter tube used was slightly conical so that when it was forced into the hole a good capillary connection was established between the soil and the walls of the tube. After standing for a given period the exhausted two-liter bottle was detached and the water which had been drawn into the apparatus was removed and measured. The water thus removed was taken to represent the amount which the soil had been able to supply to the tube during the period. By means of this apparatus it was possible to determine the rate at which a given soil could supply moisture to an artificial root (represented by the porcelain tube) and made possible the comparison of the rates of capillary movement in different soils under field conditions.

Recently Professor Montgomery, of the Nebraska Experiment Station, enclosed large blocks of soil for the purpose of studying the behavior of soil moisture, but we have been unable to find any account of this work.

In April and May, 1911, the writers succeeded in isolating in their natural field condition two blocks of Miami loam soil 3½ feet square and 4 and 6 feet deep respectively. The isolation of these blocks of soils was accomplished by digging a deep trench on two sides (Pl. I Fig. 1) and tunneling under at the proper depth. The blocks were allowed to remain in contact with the adjacent soil on two sides until a heavy plate of galvanized iron had been inserted under the soil and securely supported by means of a cement concrete pier. The blocks

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[4] Briggs, L. J., and McCall, A. G. An artificial root for inducing capillary movement of soil moisture. Science, n. ser. 20: 566–569. 1904.

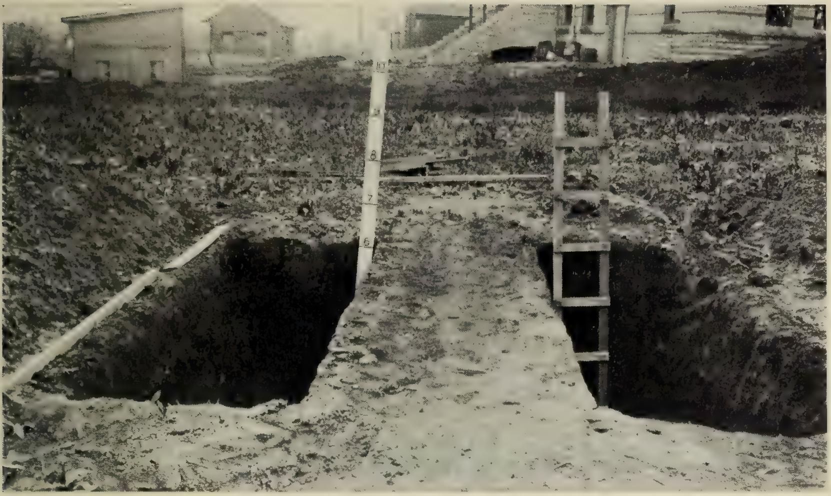

FIG. 1.—The blocks of soil cut down on two sides and isolated from the soil below by means of a tunnel.

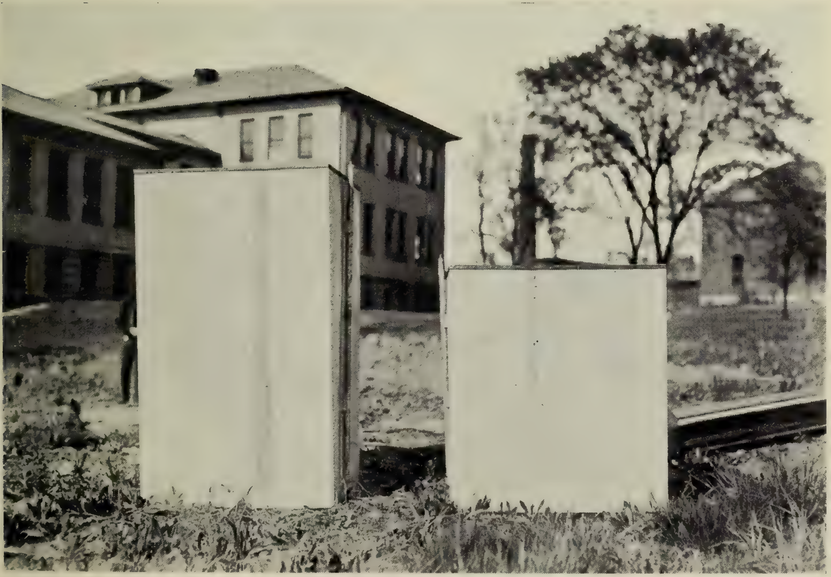

FIG. 2.—Galvanized iron tanks (without bottoms) ready to slip down over the blocks of soil.

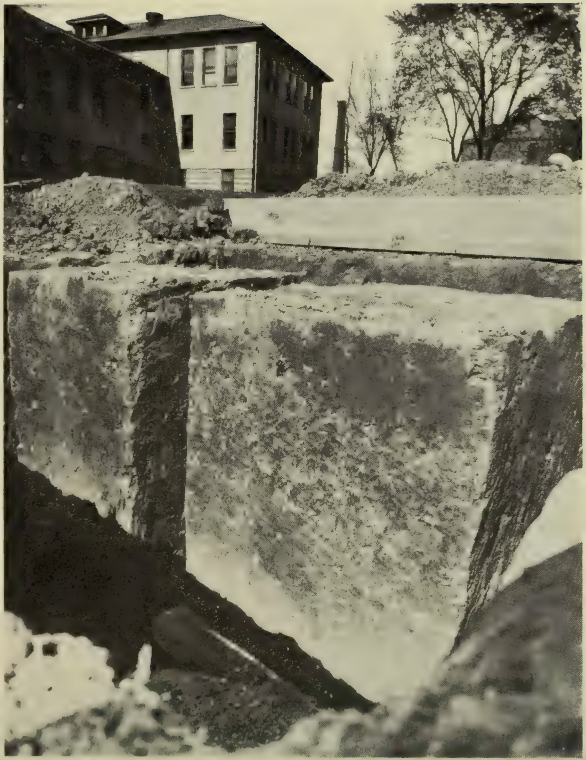

FIG. 1.—The blocks of soil cut free and resting on a sheet of galvanized iron supported by a cement pier.

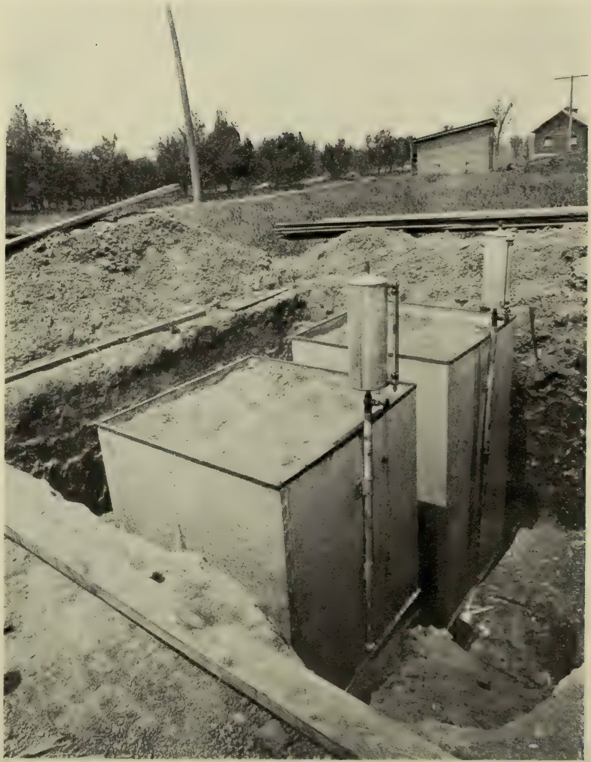

FIG. 2.—The tanks in position, showing the siphon attachment.

were then cut free (Pl. II, Fig. 1) and a case of heavy galvanized iron (Pl. I, Fig. 2) slipped down over the block until it rested on the galvanized iron plate at the bottom. The watertight joint between the casing and the bottom was secured by a crimped and soldered joint. By this means blocks of soil were securely cut off from all contact with the surrounding soil. Before the trenches were filled a stand pipe was erected on the outside (Pl. II, Fig. 2), but connected with the interior near the bottom, the opening into the tank being protected by means of a fine wire screen. The purpose of this standpipe was to enable us to maintain the water table at any desired level within the tank. The siphon tank with an outlet tube extending down into the standpipe has enabled us to maintain our water table at a given height automatically and at the same time measure the amount of water used during given intervals.

Plates I and II show the construction of this system, and the steps involved in the isolation of the blocks of soil without disturbing their natural field condition.

During the past season one hill (two stalks) of corn was grown in each of these tanks, the water table being maintained at the depth of 5 feet in one and 3 feet 6 inches in the other. The tanks were supplied with water on May 19 and the corn was planted on the same day. During the growing season all rainfall was excluded from these blocks by means of light frames covered with tarred paper. These frames were built in two sections, which when brought together formed an A-shaped covering, with an opening at the apex for the accommodation of the corn plant. The covers were made practically watertight at this point, by means of a strip of oilcloth which was wrapped around the corn plants after the frames were placed in position. The point of contact between the plants and the oilcloth was made waterproof by the use of vaseline.

It is hoped by means of these tanks to study the capillary movement of soil moisture and the behavior of soluble salts in the undisturbed field soils.

During the present season samples have been taken once each month and the percentage of moisture and the nitrates determined for each foot. The daily loss of moisture from each tank was measured by the amount of water required to maintain the water table at a given height. An open tank equipped with siphon arrangement for maintaining the water table was sunk into the soil near the soil tanks. By this means comparison was made between the evaporation from the free water surface and the surface of the soil.

During the early part of the season the plants made approximately normal growth, but later in the season they became dwarfed and did not come to normal maturity. The tight cover used to exclude the rainfall was, in part, responsible for the failure of the plants to come to maturity. During a long, rainy period late in August, the plants were attacked by a mould and all of the lower leaves dropped off. For the coming season we expect to substitute some form of open tent for the tarred paper frames.

The work of the past season has been preliminary. Our experience has suggested but one change in the form of the apparatus, namely, the substitution of the tent for the tarred paper covering. In our work a layer of sand and gravel was encountered at the bottom of our 6-foot block, otherwise it would have been necessary to have supplied a layer of this material in order to insure a free movement of the water from the opening of the stand pipe and an equal distribution under the blocks of soil.

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# THE PRACTICAL CLASSIFICATION OF SOILS.

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(Contribution from the Department of Soil Technology.)

### *Relation of the Soil to Agricultural Practice.*

The comprehensive study of agricultural questions which has arisen in recent years has revealed the necessity for accurate information on the character and distribution of soil conditions. It is being more clearly recognized how fundamentally the soil enters into all questions of agricultural betterment both scientific and practical. Not only does the intelligent management of the soil rest upon a proper appreciation of the inherent physical, chemical and biological variations in soils in different parts of the country, but the suitability of these to different crops, the adjustment of the crops which can best be produced to the business organization of the farm, its size, equipment, money product, transportation and market facilities, and the social life of the community are involved. The application of the results of the investigation of the institutions for agricultural research,—the Experiment Stations, the Colleges of Agriculture and the Federal and State Departments of Agriculture must take account first of all of soil conditions. Types and varieties of crops, methods of culture, tillage, drainage, irrigation, and fertilization give better results upon some types of soil than upon others. Those which are well suited to one soil may be a total failure upon some other soil. The experiment stations have often confined their study to one or two types of soil on the central institution farm. It is only within very recent years that the importance of carrying on investigations at substations, upon the several typical soil formations which may exist in their territory, has been recognized. In all these and many other even larger questions a knowledge of the variety and distribution of the soils of a territory is of prime importance.

### *Principles of Classification.*

The study of any group of facts or phenomena involves an understanding of the properties in which they may differ and the systematic representation of these differences requires that the properties of importance be arranged and classified with reference to some controlling interest. Soil is no exception to this general rule but the application of these principles in the field description of soils in a practical way and from the agricultural point of view presents many and complicated problems.

### *Definition of Soil.*

In the discussion of the classification of soils, the soil should be viewed very broadly so as to include any portion of the earth's surface capable of producing plants. It includes thin, stony material as well as that of great depth and friability. It includes desert regions as well as humid sections. In includes the material as deep as any influence is exerted upon plants growing on the surface.

### *Requisites of Scheme of Soil Classification.*

The classification of soil to be of the largest value should effect the accurate separation of materials with reference to all important inherent agricultural differences. This statement indicates the breadth of the point of view to be taken. It is that of the farmer, agriculture in its broadest sense. The classification should not be confined to any particular section of plant production. It should apply to flowers and forests as well as to wheat and cotton. It should have a place for the roughest mountain region as well as for the most intensively tilled garden. To be less comprehensive is to invite arbitrary judgment and corresponding inaccuracy in the application of the scheme in the field. The distinctions with reference to plant growth and agricultural practice, which should be made are differences in:

first, chemical composition, including total content of plant food, amount of lime, amount and condition of the organic matter and the solubility of all these, including the presence of alkali salts; second, physical properties including texture, structure, color, moisture, capacity, aeration and temperature; third, the climate under which these properties exist. These distinctions which will determine natural plant growth will also make sufficient provision for agricultural practice necessary to produce domestic crops.

The ideal result of the scheme of soil classification is to separate all soil material into types or individuals which are uniform in their agricultural value and distinct from every other type of soil. The soil type must be the unit and the primarily important separation in the scheme. Once the types are recognized they may be grouped according to any selected properties, irrespective of those involved in arriving at their identity.

### *Difficulties in the Field Separation of Soils.*

Having pointed out the properties with reference to which soils should be classified the next problem is to apply these in a systematic way in the field. Herein arise two kinds of difficulties. First, to classify soils directly by their properties for plant growth is impracticable. Take chemical composition for example. To classify soils upon the basis of chemical analysis of samples of every acre or even every ten acres is impracticable because of the large amount of labor and time involved. To directly determine the moisture capacity, temperature and other essential factors of plant growth presents similar practical difficulties. The direct method must, therefore, be set aside. The important crop-producing properties must be correlated with some group of characteristics of the soil which are more easily recognized and grouped, and by this means may be distinguished types of soil which have some measure of agricultural unity and value. The more perfect this correlation of properties the more satisfactory will be the result. The characteristics of the soil which have been most often selected for correlation with its crop-producing properties are the geological.

The second group of difficulties lies in establishing the correct relation between crop-producing power and geological origin, and also in the accurate separation of soil material along geological lines, due to the complexity of the geological processes and materials involved. Attention should be directed here to a point often overlooked, namely, that the separation of soils along geological lines is secondary to their separation according to crop-producing power. The method is an incident to the result however interesting it may be as a part of the science of geology. Much confusion in work has resulted from the failure to sense this distinction. The soil type is a geological element in the structure of the earth and as such is legitimately investigated by the geologist. Unfortunately for agricultural purposes the geologist has seldom carried his separations far enough, due probably to the fact that he has not had the agricultural point of view and, therefore, has not appreciated the kind of distinctions which are demanded for farming purposes. This may be termed the agronomic point of view.

### *Principles Which Have Been Used in the Classification of Soils.*

The soil has been classified from many points of view. Emmons[1] studied the soils of New York between 1835 and 1840 and made somewhat extensive chemical analyses of the soils in the several regions into which the state was divided. This is probably the most extensive of the early surveys and combined the chemical composition with geological origin in arriving at the agricultural separation, a method generally employed by investigators working in this field. The physical properties of the material were also recognized as important but these several factors were not correlated in any definite way. Owen and Peters[2] made a very comprehensive study of the chemical composition of the soils of Kentucky. Hilgard[3] has made the largest collection of the chemical analyses of soils available in America in connection with the investigation of the cotton soils and the soils are classified in the field and indicated on maps with reference to the native vegetation. The mode of formation and physical properties received consideration. Shaler[4] in an article published in 1891 called attention rather definitely to the relation between the processes of soil formation and the character of the material and pointed out correlated types of plant growth.

In foreign countries a number of men have studied the problem of the practical classification of soils and of these the Russians have been most successful. Dokouchayev with his pupils,[5] the most prominent of whom is Sibertzev,[6] studied these questions for many years and arrived at what may be termed the most perfect and comprehensive scheme devised up to the present time. Theirs is a genetic system based upon climate, the formation of the soil, and the apparent properties. It was rather a statement of broad groups than the designation in systematic order of the factors which give rise to agricultural differences in soils.

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[1] Emmons, Ebenezer. The Soils of New York. Natural History of New York Agriculture I: 207–360 (1843), 1846.

[2] Owen, D. D. Geological Survey, Kentucky. Annual Repts. 1855–1875. Peters, Robert. Chemical Composition of Soils, Marls, Ores, etc., Chemical Analysis *A*, Pts. I–II–III, 1875–1888.

[3] Hilgard, E. W. Cotton Production. 10th Census, V and VI, 1880.

[4] Shaler, N. S. Origin and Nature of Soils. 12th Ann. Rept. U. S. Geol. Surv., Pt. I: 219–345, 1890–91.

The credit for definitely correlating the physical properties of the soil with its agricultural belongs chiefly to Whitney[7] and his associates. By his work the textural properties of the soil, through their influence on the moisture capacity and general climate of the soil, were shown to have a very determinate effect on the crop-producing power of the soil. The adaptation of natural vegetation and of domestic plants largely reflects these properties. Grass is shown to be generally identified with fine textured soils, corn with loams and truck and other special crops with rather light sandy loams.

## *The Federal Soil Survey.*

In 1899, as chief of the United States Division of Soils, Whitney began the classification and mapping of soils in the field according to their evident agricultural value. At first the physical properties were used almost exclusively as the means of separation. This survey work expanded and many men were employed in the field. Gradually the scheme of classification expanded under the lash of necessity, keeping always to the fore the agricultural significance of each separation. Over four hundred thousand square miles were surveyed up to the beginning of 1911, distributed more or less in every state in the union. These surveys have proved their value and more than anything else have demonstrated the necessity of such work as a basis in general agricultural investigations and in education. They have also exemplified the necessity of arriving at definite principles for the classification of soils which in their distribution have little relation to political boundaries. Following the lead of the federal government and as a supplement thereto, many of the states have taken up survey work, some independently and some in cooperation with the federal bureau. All this emphasizes the need of a common basis for

[5] Tularkov, N. The Genetic Classification of Soils. Jour. Agr. Sci. 3: 80–85, 1908.

[6] Sibertzev, N. Expt. Sta. Record 12: 704–712, 1900; 807–818, 1901.

[7] Whitney, M. U. S. Weather Bureau Bul. 4.—Also Buls. S. C. Agr. Exp. Sta., Md. Agr. Exp. Sta. and U. S. Bureau of Soils.

work, such as the committee on soil classification of the American Society of Agronomy is endeavoring to establish.

While of great value and proceeding upon a broad basis of separation of soil types designed to represent their chief agricultural differences, on the one hand, the work has not always been as accurate as it might have been and, on the other hand, it has not been properly understood or appreciated because the factors which are used in the classification of soils have never been accurately stated. Individual survey men have been left very largely to absorb the scheme of separation from contact with the older men in the Bureau and to work it out for themselves from previous training and especially from experience in the field. Apparently the factors which are used in the separation of soils are not always recognized and the grouping of types is often not upon parallel lines or lines of equal significance. The properties which determine differences in value have not been clearly perceived. The corollary of inaccurate grouping is inaccurate boundaries of soil types. As an instance of the first inaccuracy the Coastal Plain is put on a par with the soils of glacial formation, however justified this may seem to be from the point of view of agricultural prominence. In the same line is the classification of material occurring in the Ohio river bottom in Mason county, Kentucky, with the Norfolk series which is a part of the Coastal Plain. (Since changed.) The most serious errors in drawing the boundaries of individual types result from failure to appreciate the factors upon which the larger separations are made. These difficulties are pointed out, not to minimize the value of the work done, for they weigh lightly against the large and fundamental value of the surveys which have been completed and which in the main are sound, but rather with the purpose to illustrate the importance of stating as clearly as possible the factors which are used in the practical classification of soils and the comparison of these with what may be termed an ideal scheme of classification. It is objected by some persons that it is not possible to devise a perfect scheme which is applicable under all conditions. The important point is rather that we now have a fair understanding of the primary factors which produce agricultural differences in soil and that the use of these in the classification, representation and study of soils is of great practical value. We shall attain nearer a perfect system as we accumulate more information on the subject. All of the elements of soil separation which are mentioned in the following pages have been employed in the work of the Bureau of Soils but they have not been given equal or uniform value.

The most comprehensive review of the methods which have been used in the classification of soils is that by Coffey, prepared as a thesis for the Master's degree in George Washington University under the direction of Dr. George P. Merrill.

The aim of this paper is to organize the factors which have been used in the classification of soils and any others which appear to have a controlling influence on the agricultural value of soil into a scheme which shall point out the fundamental factors involved, and the relation of these factors to the distribution of soils in the field. The requisites and some of the limitations of such a scheme have been stated. It was noted that the crop-producing power of a soil is dependent upon its chemical and physical properties and the climate.

### *Statement of Plan of Classification.*

The climate of a soil has two phases: first, the climate of the region in general due to its geographical position, and, second, the climatic conditions within the soil due to the physical and chemical properties of the soil itself. Due to the latter, two soils of different properties situated under the same general climatic conditions may present different climatic conditions to the plants growing upon them. The temperature and humidity of sand and clay may be very different which is illustrated by the fact that one is termed an "early" soil and the other a "late" soil.

The physical and chemical properties of a soil are due to its mode of formation and the kind of materials used. The first include the time element or extent of operation of the processes and changes subsequent to the general formation of the material such as drainage, climate, etc. The second include the kind of rocks from which the soil material is derived and may be as diverse as the kinds of rock multiplied into the proportionate mixture of any combination of these. The scheme is, therefore, genetic and in its broader lines purely geological. The relation of these to agricultural properties will be indicated as the scheme is developed.

### *Climate.*

The broadest agricultural divisions in soil are due to climate. Although the soil material were the same (if that is possible) if it occurred under widely different conditions of climate it would have a different agricultural value and should be differentiated.

Climate consists of two primary elements. These are temperature and humidity, or precipitation.

1. *The Region—Temperature.*—We propose to term the groups of

soils determined by temperature the *region* and the surface of the earth would be divided into belts or zones corresponding in general to those commonly made and these may be multiplied if their agricultural diversity proves too great. The temperature has some influence upon the type of processes by which soils are formed and the changes which they are continually undergoing.

2. *The Section—Humidity.*—The groups determined by humidity we would term the section and the temperature zones would be subdivided according to the degree of aridity. In the United States three conventional groups have been recognized, namely, the humid, the semi-arid and the arid. Humidity has an especially marked effect upon the processes of soil formation and bring about distinct physical and chemical differences. In a general way in arid regions physical processes of the decay of rocks are relatively more prominent than chemical processes, resulting in soil which averages coarser in texture. Alkali or the excess of soluble salts is chiefly identified with aridity of climate. These are, therefore, broad distinctions in the properties of soil which should be recognized.

3. *The Province—Mode of Formation.*—The third great factor which determines the properties of a soil is the mode or process of formation. This includes all the processes and forces which have been operative in transforming rocks into soil and imparting to them distinctive physical and chemical characteristics. These are dynamic and, therefore, impress special properties upon the material handled. While several processes are usually operative on the same material they are seldom equally prominent and certain conventional groupings have been adopted by geologists, especially those who have given much attention to soils, for example, G. P. Merrill.[8] These are (*a*) general weathering which gives rise to residual material. The type of weathering and the activity of the several forces will depend upon the kind of rock. (*b*) Decay acting upon organic material to give rise to cumulose deposits. It differs from weathering since there is an actual building up of material due to biological activity and biological changes are dominant. These two groups taken together have been termed the *sedentary division,* since the material has not been appreciably moved. Where rocks are involved the soil is likely to rest on rock of the same kind as that from which the soil was formed. The physical as well as the chemical properties of the rock maintain considerable of their identity in residual soil. For example, quartz bands in gneiss rock and chert masses and other impurities in the different strata of limestone.

[8] Merrill, G. P. Rocks, Rock-weathering and Soils, pp. 411, 1897. Macmillan Co., N. Y.

The remaining processes involve appreciable transportation of the material and have been grouped together as the *transported division.* Four great agencies of transportation are recognized.

(*c*) Gravity produces the slow sliding of material down rather steep slopes and in some instances it includes avalanche movement. The material is without organized structure and likely to be rather coarse and thin and of low agricultural value in both extent and adaptation.

(*d*) Water has been the great transporting and soil-forming agency. Many of the most famous agricultural portions of the earth owe their formation to water, notably the Nile valley, the American coastal plain, and the interior lake plains and stream valleys. It couples a wide range of transporting power with very decided sorting and in the deposit of the material produces stratification. Thereby nearly all of the areas of soil of distinct textural unity have been derived. Fine clay and clean, uniform sand are equally identified with the agency of water. Stratification implies differences in successive layers, and a shift in the direction or velocity of movement of the water when a material was being laid down may produce great variation in texture, structure and chemical composition. These principles of variation are so well understood that much explanation is unnecessary.

It is worth while to recognize three phases of action of water according to its breadth, extent of movement and to some degree its character. These are oceans (saline waters), lakes and streams. The depth, uniformity and chemical character of the soil formed under each of these influences are likely to be distinct. While water gathers rock material from many sources each body is likely to have certain characteristics of its material due to the region drained.

(*e*) Ice in the form of glacial masses has been an extensive and important agency of soil formation adjacent to the polar regions and in high mountains. Some of the most famous agricultural portions of the world such as much of the Upper Mississippi river valley owe their character to this agency. Here again peculiar chemical, physical, and to some extent, topographic features are imparted to the material handled. The kind of rock encountered, the rate and direction of movement of the ice and the minimum of chemical decay and leaching have determined the agricultural features of many regions formed by glacial ice. The soil conditions in New York State especially exemplify these distinctions.

Ice does not accomplish sorting or stratification and is likely to produce a range in texture and a degree of compactness of the lower part of the soil section not found in soils formed in other ways. It is often difficult to distinguish between material deposited by pure ice action and that modified by glacial water due to the melting of the ice.

(*f*) Wind has not been so distinctly a soil-forming agency as water and ice, though it has very generally contributed to the result.[9] Like water it effects sorting and stratification but the range in texture of material carried is very much more narrow, the type of stratification is different, the material has a wider areal unity in chemical and physical properties. The most distinctive soil formations whose origin has been referred to the action of wind are sand dunes and loess. The former represents a large amount of material which has been rolled along the surface of the ground. It is usually a fine sand and shows sorting to the extent that very fine material is almost wholly removed. While the origin of loess has been referred to the settling of dust from the atmosphere the American deposits exhibit properties which cause the adequacy of this theory to be questioned. In northern China where this material was first recognized its origin was attributed by Von Reichtofen to the agency of wind. At any rate it is a distinct material and seems more closely associated with this mode of formation than any other. The possible chemical and physical properties of wind-blown material entitle it to recognition in the scheme of classification.

4. *The Group—Source of Material.*—The kind of rock or rocks from which a soil is formed is generally recognized to have a large influence on its chemical and physical properties. The mineral character of the rock and the extent of decay determines the texture of the soil, the composition of the rock influences both the composition and texture of the soil in a distinctive way. The same rock may be transformed into soil by several agencies and again the same agency may act on several kinds of rock. The product is likely to be equally diverse in its capacity to support plants. A large variety of rocks might be recognized as influencing the character of soils. The fact that soil has usually been derived from quite a variety of rocks, makes it necessary to keep the divisions here as broad as possible since only these can be recognized with any degree of accuracy. These are rather large groups and in practice special distinctions are likely to be made on this basis. The primary groups to be recognized may be mentioned as acid and basic rocks of igneous origin (and with these the gneisses, schists and similar secondary rocks are likely to be

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[9] Free, E. E. The Movement of Soil Material by the Wind. U. S. Dept. Agr., Bur. Soils, Bul. 68: 1–272, 1911.

included), shale and slate, sandstone and quartzite, limestone and marble. Plant remains constitute a separate and distinct class of material from which soil may be formed and the proportion of these which enters into any given formation may give distinctive character.

Often the mingling of material from several kinds of rock may impart peculiar character to the soils of a drainage system or a lobe of glacial ice. The red alluvial soils of the Red River drainage system owe their character largely to the red Permian formations of Oklahoma and Texas. The glacial soils of west central New York are largely dependent for their character upon the several shale, limestone and sandstone rock formations crossed by the ice in reaching that position. The line of movement of the material with reference to the general rock structure will largely determine the relation of the soil to any particular rock formation.

5. *The Series.*—The soil series is the most complex of the separations made in practice. Unlike the others it does not rest upon a single character. Its separation requires the employment of a group of correlated characters. These are more intimate in their nature, more concerned with the material itself than the bases of the larger separations. Having applied those the final grouping of types or units is determined first of all by

(*a*) *Color.*—Color as a physical property is not of great importance, but when considered in connection with the properties which are correlated with color it is of the greatest significance. Color is usually indicative of the proportion of organic matter, of the drainage, of the state of oxidation, of the proportion of lime carbonate and, to a degree, of the mineral composition of the soil.

(*b*) *Organic Matter.*—The proportion of organic matter is suggestive of the nitrogen content of the soil. It has a large influence on the availability of the mineral particles. It is indicative of the natural drainage, of the proportion of lime carbonate and of the activity and type of micro-organisms.

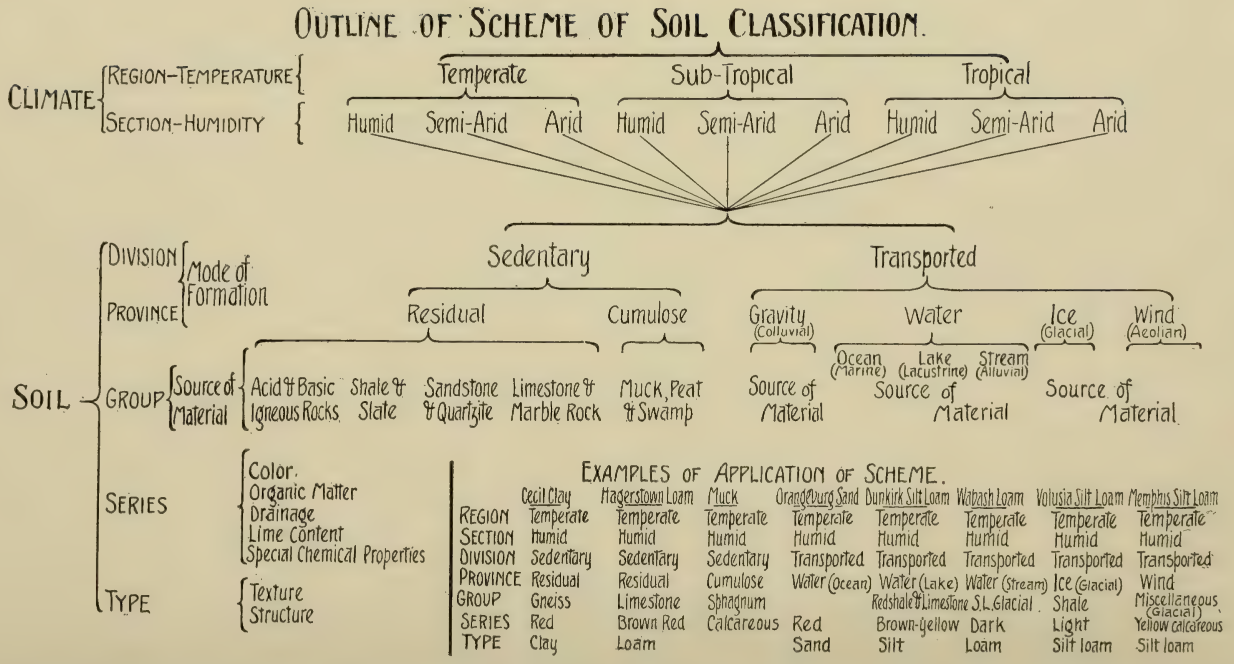
(*c*) *Lime Carbonate.*—The presence of a fair amount of this constituent has been pretty generally recognized as essential to a fertile soil.

(*d*) *The Total Plant Food Content of the Soil.*—While the average soil contains a relatively large quantity of the mineral plant food constituents, soils which are decidedly deficient in some one or more of these are sufficiently abundant to warrant the special consideration of this property. It does not necessarily involve general chemical analysis and may often be inferred from other properties. The solubility of the soil constituents while seldom a distinctive basis of series separation is often indicative of other characteristics of the soil and as alkali, especially, of the type of climate. These several elements will seldom, if ever, have equal value in deciding a separation. They can not well be applied independently in general field work. In some cases one, as color, may be dominant, in another drainage, and in still other separations it may be the lime content which will determine the grouping.

If one consider all soil series together without reference to their grouping according to the broader bases of classification, such as formation, etc., it will generally be observed that soil series are chiefly distinguished by chemical differences, that is, differences in composition and chemical form. Organic matter is suggestive of the nitrogen content, solubility, etc. The presence of lime is a matter of composition. Differences in rock material mean certain differences in composition. On the other hand the last or unit separation of soils is based chiefly on physical properties—texture and structure. The series includes all material having the same characteristics but varying in texture from the coarsest to the finest.

6. *The Type–Texture and Structure.*—The fineness of the material of which a soil is composed is the most broadly influential of the physical properties of a soil. Through its influence on porosity, moisture relations, aeration, temperature, tillage properties, etc., it is probably the most dominant in deciding crop adaptation and agricultural value. The more distinct textures of clay, loam, silt, and sand are generally recognized. These rest upon the proportion of particles of different sizes and a great variety of proportions may be recognized and given names. These are being multiplied. A question requiring further consideration is the number of sizes of particles—separates—to be recognized and the limits of these. Several systems of groupings are now in use.[10] The finer the particles the greater is the influence of a given mass of them upon the character of the soil. Many more divisions should, therefore, be made in the fine material than in the coarse material. It is an open question whether, as survey work has been done in the United States, sufficient divisions have been made below the sand classes. Undoubtedly field separation of materials by hand examination is not likely to be more refined than is possible with the divisions now generally made. However, finer distinctions in the chemical analysis of material smaller than 0.005 mm. may explain some variations in types of soil not otherwise recognized and these form the basis for more detailed study of individual types.

[10] Briggs, L. J., et al. The Mechanical Analysis of Soils. U. S. Dept. Agr., Bur. Soils, Bul. 24, 1904.



EXAMPLES OF APPLICATION OF SCHEME.

| | Cecil Clay | Hagerstown Loam | Muck | Orangeburg Sand | Dunkirk Silt Loam | Wabash Loam | Volusia Silt Loam | Memphis Silt Loam |
|---|---|---|---|---|---|---|---|---|
| REGION | Temperate | Temperate | Temperate | Temperate | Temperate | Temperate | Temperate | Temperate |
| SECTION | Humid | Humid | Humid | Humid | Humid | Humid | Humid | Humid |
| DIVISION | Sedentary | Sedentary | Sedentary | Transported | Transported | Transported | Transported | Transported |
| PROVINCE | Residual | Residual | Cumulose | Water (Ocean) | Water (Lake) | Water (Stream) | Ice (Glacial) | Wind |
| GROUP | Gneiss | Limestone | Sphagnum | | Redshale & Limestone | S. L. Glacial | Shale | Miscellaneous (Glacial) |
| SERIES | Red | Brown Red | Calcareous | Red | Brown-yellow | Dark | Light | Yellow calcareous |
| TYPE | Clay | Loam | | Sand | Silt | Loam | Silt loam | Silt loam |

FIG. 1.—Diagrammatic outline of the scheme of soil classification showing the relation of the separations suggested; also several illustrations of the application of the scheme to particular soil materials.

The structure of a soil as determined by the order of stratification and the thickness of the layers may also be the basis of type separation. This is independent of general structural differences due to the general mode of formation and the characters of the rock.

The soil type is the unit for soil study and should be as nearly alike in all parts as is possible. It is the most important grouping of material primarily because it does represent the chief physical differences in soils. The next most important grouping is the soil series and these two will be most generally identified with particular crop and agricultural interests in practice. This does not minimize the value of the larger separations which, as has been suggested, are essential to reasonable accuracy in these last two groups.

Of course the final test of a survey must be in the field man who applies these principles to a particular set of conditions. Owing to the intimate overlapping of several fields of natural science in this work it is evident that he should be a man of broad training including especially geology and the principles of soil fertility and he should have keen power of observation and correlation. Scarcely any experience or training which the field man may possess but finds use in the ideal soil survey man.

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# SOME EXPERIMENTS TO ESTIMATE ERRORS IN FIELD PLAT TESTS.

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(Contribution from the Department of Soil Technology.)

Methods for the conduct of field experiments have received, until recently, little experimental investigation. Such investigation requires much time and land, which is thus lost to the solution of the farmers' problems, or at least to their apparent solution. Unfortunately the methods and the problems cannot usually be worked out at the same time and on the same piece of land. The study of methods has been left for the time when the experiment stations have proven their value to the public. The large number of papers on methods of field experimentation presented to this Society during the past two years indicate an appreciation of the importance of the subject by the agronomists of the country.

Errors in field plat tests may arise from a large number of sources. These may be classed under three divisions:

1. Errors arising from soil.
2. Errors arising from the plant.
3. Errors arising from external agencies.

This paper does not attempt to cover all sources of error, but devotes itself merely to those phases of the subject on which experimental data have been secured, or which lend themselves to mathematical treatment.

## Errors Due to Soil.

It is impossible to secure a perfectly uniform soil for field experiments. Differences in the productive capacity occur in all portions of the field, the larger differences in productivity being indicated by differences in topography, humus content, structure or texture which can be distinguished by the eye, but the smaller differences may not be accompanied by any ocularly appreciable differences. Even on very small areas of land variations occur, so that it is impossible to say that any plat of land is uniform in the productivity of its different portions or that it is coordinate with any other plat.

It is, furthermore, quite likely that the productivity of a certain plat changes from year to year and that, even under what we consider to be the same treatment, the adjacent plats of a series will not maintain their respective productive capacity two years consecutively, so sensitive is the soil to tillage given during certain stages of moisture content, or done with greater or less thoroughness.

Unfortunately the number of attempts to test the uniformity of land and the accuracy of results, by means of experiments especially designed for that purpose, have been few. During the early years of the Association of Agricultural Colleges and Experiment Stations, considerable discussion was given to the subject, but it resulted in only a few direct experiments.

Davenport and Fraser report[1] an experiment with 77 varieties of wheat grown on plats two rods square. In addition to the plats having different varieties were nine check plats planted to the same variety. These were distributed uniformly among the others. So great was the variation on the check plats that only eight varieties yielded higher than the highest yielding check, and but three varieties lower than the lowest yielding check. I mention this merely as an illustration of the lack of uniformity in land that was selected for field plats because of its apparent uniformity.

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[1] Davenport, E., and Fraser, W. J. Experiments with wheat 1888–1895. Illinois Exp. Sta. Bul. 41: 147–160, 1896.

## *Changes in the Relative Productiveness of Plats in Different Years.*

At the Nebraska Experiment Station a series of twenty-four plats was laid off on land that was apparently uniform. These plats were 33 × 66 feet in size, making one-twentieth acre each, and lay in three rows of eight plats each, the shape of the entire series being thus nearly a square. Each row of plats received the same treatment and was planted to the same crop for the years 1900–1907 inclusive.[2] No

TABLE I.—*Yields and Relative Productiveness of a Series of Plats Through a Number of Years.*

| Plat No. | Yields of Crops on Plats, in Pounds. | | | | | | | Relative Productiveness for Each Year. | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Oats, Dry Wt. | | Oats, Grain. | Oats, Grain. | Corn, Grain. | | | | | | | | |
| | 1900 | 1901 | 1902 | 1903 | 1905 | 1906 | 1907 | 1900 | 1901 | 1902 | 1903 | 1905 | 1906 | 1907 |
| 57 | | 91 | | 118 | 123 | 210 | | | 7 | | 4 | 4 | 5 | |
| 58 | | 137 | | 124 | 109 | 225 | | | 3 | | 3 | 8 | 4 | |
| 59 | | 92 | | 130 | 124 | 195 | | | 6 | | 1 | 6 | 6 | |
| 60 | | 73 | | 126 | 136 | 225 | | | 8 | | 2 | 1 | 3 | |
| 61 | | 151 | | 117 | 128 | 230 | | | 1 | | 5 | 2 | 1 | |
| 62 | | 114 | | 114 | 123 | 180 | | | 4 | | 7 | 5 | 8 | |
| 63 | | 137 | | 116 | 112 | 190 | | | 2 | | 6 | 7 | 7 | |
| 64 | | 101 | | 109 | 126 | 230 | | | 5 | | 8 | 3 | 2 | |
| | Corn, Grain. | Corn, Dry Wt. | | Corn, Grain. | Corn, Grain. | Oats, Grain. | Corn, Grain. | | | | | | | |
| | 1900 | 1901 | 1902 | 1903 | 1905 | 1906 | 1907 | 1900 | 1901 | 1902 | 1903 | 1905 | 1906 | 1907 |
| 65 | 150 | 17.6 | | 255 | 255 | 103 | 300 | 2 | 8 | | 5 | 2 | 7 | 4 |
| 66 | 160 | 18.2 | | 282.5 | 255 | 129 | 360 | 1 | 7 | | 4 | 1 | 3 | 2 |
| 67 | 146.5 | 34.2 | | 301.3 | 250 | 109.8 | 365 | 3 | 5 | | 1 | 3 | 6 | 1 |
| 68 | 160 | 37.6 | | 287 | 220 | 114 | 340 | 1 | 3 | | 3 | 5 | 5 | 3 |
| 69 | 146 | 40.4 | | 230.5 | 210 | 135.5 | 240 | 4 | 2 | | 7 | 7 | 2 | 6 |
| 70 | 150 | 33.9 | | 237 | 220 | 138.5 | 225 | 2 | 6 | | 6 | 6 | 1 | 7 |
| 71 | 150 | 34.4 | | 204.5 | 205 | 128 | 165 | 2 | 4 | | 8 | 8 | 4 | 8 |
| 72 | 145 | 42.5 | | 299.3 | 235 | 94 | 247.5 | 5 | 1 | | 2 | 4 | 8 | 5 |
| | Oats, Grain. | Corn, Dry Wt. | Oats, Grain. | Corn, Grain. | Corn, Grain. | Oats, Grain. | Wheat, Grain. | | | | | | | |
| | 1900 | 1901 | 1902 | 1903 | 1905 | 1906 | 1907 | 1900 | 1901 | 1902 | 1903 | 1905 | 1906 | 1907 |
| 73 | 82 | 31.3 | 62 | 308.3 | 250 | 82 | 87.5 | 3 | 8 | 3 | 6 | 5 | 6 | 6 |
| 74 | 88 | 34.9 | 77 | 300 | 250 | 81 | 79.5 | 2 | 7 | 1 | 7 | 5 | 7 | 8 |
| 75 | 80 | 39.4 | 65 | 325 | 265 | 95 | 95 | 4 | 6 | 2 | 4 | 4 | 4 | 3 |
| 76 | 56 | 41.5 | 54 | 330 | 275 | 107.5 | 93 | 6 | 5 | 5 | 3 | 2 | 1 | 4 |
| 77 | 82 | 56.9 | 50 | 315 | 240 | 79 | 90 | 3 | 3 | 6 | 5 | 6 | 8 | 5 |
| 78 | 80 | 62.2 | 56 | 340 | 275 | 98 | 96 | 4 | 2 | 4 | 2 | 2 | 3 | 2 |
| 79 | 75 | 54.0 | 33 | 345 | 280 | 100 | 96 | 5 | 4 | 8 | 1 | 1 | 2 | 1 |
| 80 | 89 | 63.8 | 39 | | 270 | 87.5 | 84.5 | 1 | 1 | 7 | | 3 | 5 | 7 |

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[2] I am indebted to Professor Montgomery for the data from these plats in 1906 and 1907.

fertilizers were applied, but a dressing of manure was applied from time to time to all plats alike. The object of the test was to ascertain the relative productiveness of the plats preparatory to using them for fertilizer experiments. The crops were corn, oats, and wheat. Table I gives the relative yields of the several plats and the order of their productiveness each year, the plat yielding most being ranked 1, the next 2, etc.

One would naturally think that the plats yielding most in one year would maintain a similar standing in others, or in other words, that their relative productiveness would be nearly constant from year to year. This, however, is far from being the case. The factors other than soil governing the accuracy of field experiments were without doubt partly instrumental in producing the irregularities, but it seems certain that soil productiveness was largely responsible for it. At any rate, it illustrates the difficulty in obtaining accurate results from field experiments, and to my mind demonstrates the great influence which very slight differences in soil structure may have upon its productivity. Such factors as the condition of the soil on different plats at time of plowing, or of other cultural operations, may produce great differences in yield.

### *Size of Plats.*

So far as the dimensions of field plats are concerned there are two classes of experiments to consider: (1) Those having to do with soil treatment, (2) those designed to determine some property of the plant apart from its relation to any particular method of soil treatment.

In experiments of the class first mentioned it is evident that there must be enough soil to permit the operations of the treatments to be tested. This prevents the use of a single row. The shape of plat usually adopted by experimenters is oblong.

Plats used for testing the effect of soil treatments are usually either one tenth or one twentieth acre in size. It has not been generally customary to repeat the treatment on two or more plats. In the most carefully conducted experiments check plats or those having similar treatments have occurred every third plat.

It seems possible that the use of smaller plats on which the same treatment is repeated several times, the replicate plats being located on different parts of the field, may have some advantages over using the larger plats.

Plats of this kind have been laid out on the experiment field at Cornell University and comparisons may be made with tenth-acre plats in the same field. The small plats are one hundredth acre in size, being 43.5 feet long and 10 feet wide. They are separated by a two-foot space. When planted to small grain this intervening space contains two rows of grain which are removed before harvest. When planted to maize one row occupies the two-foot space and this row is removed before harvest. An evident advantage in the small plat is the greater care that can be given the experiments without increasing greatly the cost.

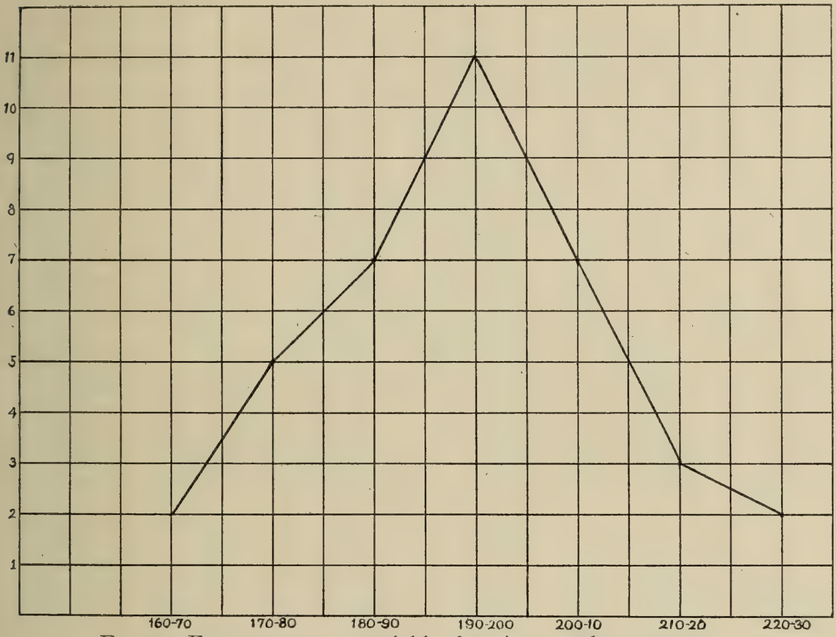

FIG. 2.—Frequency curve; yield of maize on plat 1201–1237.

In 1911 a series of these plats was planted to maize in order to test the uniformity of the land. All of plats 1,201–1,237 were given the same soil treatment. The yields of silage on these plats when plotted in a frequency curve are shown in Fig. 2. The curve is sufficiently uniform to justify the use of the figures for calculating the probable error which may be expected to occur on any plat in the series in this particular test. The crop of another year may give a different result, but a repetition of the test for a number of years should allow an approximately accurate conclusion as to the probable error which may be expected.

For the calculation of probable error the formula

$$\text{p.e.} = 0.67\sqrt{\frac{S}{n-1}}$$

has been used, in which *S* equals the sum of the squares of the percentage deviations from the arithmetical mean of the yields of the plats; and *n* equals the number of plats used in the calculation. This gives the probable error in percentage of the mean and admits of comparison with other plats. Calculated in this way the probable error for any plat in the series 1,201–1,237 when no two plats receive similar treatment (i. e., the yields from no two plats are averaged) and when no check plats are used, is ± 5.2 percent. The yields on these plats and the method of calculation are shown in Table II.

TABLE II.—*Tabulation of Steps in Process of Calculating Squares of Percentage Deviation from Mean Yield of a Series of Plats.*

| Plat No. | Actual Yield. Lbs. | Arithmetical Mean of Yield of Even Plats. | Deviation from Mean. Lbs. | Deviation from Mean. Percent. | Squares of Percents of Deviation. |
|---|---|---|---|---|---|
| 1,201 | 227 | 195 | 32 | 16.4 | 268.96 |
| 1,202 | 204 | 195 | 9 | 4.61 | 21.25 |
| 1,203 | 220 | 195 | 25 | 12.8 | 163.84 |
| 1,204 | 225 | 195 | 30 | 15.4 | 237.16 |
| 1,205 | 217 | 195 | 22 | 11.2 | 127.69 |
| 1,206 | 198 | 195 | 3 | 1.5 | 2.25 |
| 1,207 | 168 | 195 | 27 | 13.8 | 190.44 |
| 1,208 | 182 | 195 | 13 | 6.7 | 44.89 |
| 1,209 | 170 | 195 | 25 | 12.8 | 163.84 |
| 1,210 | 196 | 195 | 1 | .5 | .25 |
| 1,211 | 205 | 195 | 10 | 5.1 | 26.01 |
| 1,212 | 213 | 195 | 18 | 9.2 | 84.64 |
| 1,213 | 191 | 195 | 4 | 2.0 | 4.00 |
| 1,214 | 200 | 195 | 5 | 2.6 | 6.76 |
| 1,215 | 198 | 195 | 3 | 1.5 | 2.25 |
| 1,216 | 188 | 195 | 7 | 3.6 | 12.96 |
| 1,217 | 175 | 195 | 20 | 10.3 | 106.09 |
| 1,218 | 173 | 195 | 22 | 11.3 | 127.69 |
| 1,219 | 196 | 195 | 1 | .5 | .25 |
| 1,220 | 195 | 195 | 0 | 0 | 0 |
| 1,221 | 195 | 195 | 0 | 0 | 0 |
| 1,222 | 200 | 195 | 5 | 2.6 | 6.76 |
| 1,223 | 205 | 195 | 10 | 5.1 | 26.01 |
| 1,224 | 208 | 195 | 13 | 6.7 | 44.89 |
| 1,225 | 185 | 195 | 10 | 5.1 | 26.01 |
| 1,226 | 171 | 195 | 24 | 12.3 | 151.29 |
| 1,227 | 205 | 195 | 10 | 5.1 | 26.01 |
| 1,228 | 200 | 195 | 5 | 2.6 | 6.76 |
| 1,229 | 195 | 195 | 0 | 0 | 0 |
| 1,230 | 202 | 195 | 7 | 3.6 | 12.96 |
| 1,231 | 206 | 195 | 11 | 5.6 | 31.36 |
| 1,232 | 181 | 195 | 14 | 7.2 | 51.84 |
| 1,233 | 178 | 195 | 17 | 8.7 | 75.69 |
| 1,234 | 187 | 195 | 8 | 4.1 | 16.81 |
| 1,235 | 189 | 195 | 6 | 3.1 | 9.61 |
| 1,236 | 187 | 195 | 8 | 4.1 | 16.81 |
| 1,237 | 175 | 195 | 20 | 10.3 | 106.09 |

In order to compare the hundredth-acre plats with the larger plats a comparison of the check plats in a series of one-tenth-acre plats, which lay directly across the roadway, may be instituted. These tenth-acre plats were last planted to maize in 1908. Every third plat in the series is a check, and consequently received the same treatment. There are seven of these check plats available for calculating the probable error.

It is probably not so accurate to use plats at some distance apart for estimating the probable error as it would be to use contiguous plats, but the lack of suitable tenth-acre plats, other than the checks, necessitates this procedure.

Calculated in the same way as before the probable error for any of the check plats having an area of one-tenth acre is 6.4 percent. The very unusual case of a series of small plats giving a smaller error than a series of large ones seems, of course, to be due to abnormal conditions, but the lack of uniformity in topography and productiveness on this field may in a measure account for it, in which case it is an argument in favor of small plats on this particular field.

As this field is now being laid out in experiment plats, the study of the relative accuracy of plats of different sizes and shapes; of the effect of repeating the same treatment several times and of the distribution of the plats to which any particular treatment is given; of the frequency of occurrence and the distribution of check plats; and of the repetition of tests for a series of years, is being conducted as far as practicable on this field, but a comparison with similar data obtained elsewhere will not only be of more general interest, but will also serve to check the results obtained here.

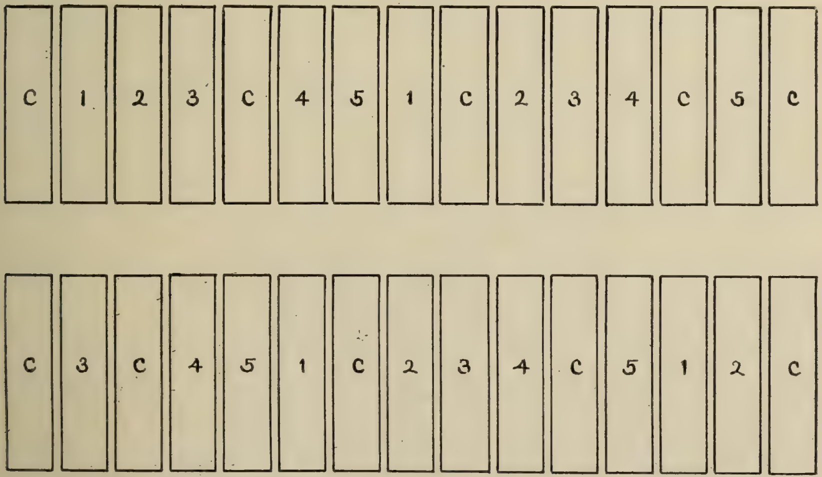

FIG. 3.—Arrangement of plats for a series of five tests. *C* indicates check plats; numerals indicate test plats. Each test repeated on the plats bearing the same number, making four replicate plats.

Where these plats are in use every third or every fourth plat is a check. Probably the arrangement to be generally followed will be to make every fourth plat a check and conduct each experiment on two adjacent rows of plats, in which system the check plats on one row are midway between those on the opposite row and no treatment is repeated on opposite plats. Each test is conducted on four separate plats. The object of this system is to give a maximum distribution of check and test plats. It is illustrated by Fig. 3.

In order to make another comparison of plats of different sizes on this field two rows of plats may be used of which plats 1,201–1,237 from one row and plats 1,401–1,437 constitute the other. The latter row of plats was also planted to maize in the same way as the former. The two rows are separated by a seventeen foot roadway with plat 1,201 directly opposite to plat 1,401, plat 1,202 opposite 1,402 and so on.

As all these plats were harvested separately and all treated alike it is possible to compare any combination of plats that may be desired. This gives an opportunity to compare the hundredth-acre plats with plats four times as large or one twenty-fifth acre, the latter being composed of four small plats. The combination of four plats gives an area of the same shape as that occupied by the single plat. This arrangement is shown in Fig. 4.

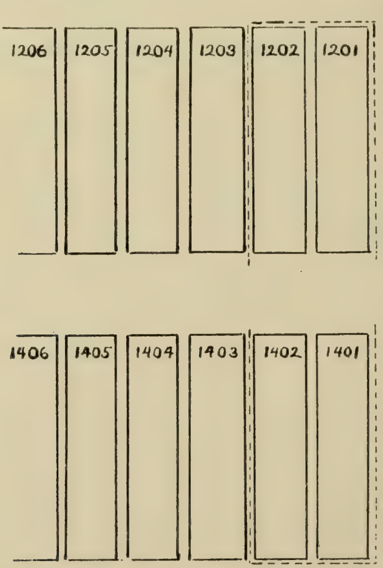

Fig. 4.—Method of combining small plats to make larger. Hundredth-acre plats are shown in solid lines and the combination of four of these into one twenty-fifth acre plat is shown by the dotted line. Both sizes of plats have the same shape, if the roadway is excluded.

The probable error for any one plat in the series 1,201–1,234, 1,401–1,434, when each hundredth-acre plat is considered as a unit, is 4.6 percent; when four plats arranged as in Fig. 4 are taken as a unit the calculated error is 4.5 percent. In this case again there is no apparent advantage, so far as accuracy is concerned, in the use of the larger plats.

TABLE III.—*Yield in Pounds from 34 Rows of Potatoes, Each Row Divided into Six Sections.* (McCloskey.)

| Sections of Row. | | | | | |
|---|---|---|---|---|---|
| *A* | *B* | *C* | *D* | *E* | *F* |
| 20.5 | 17.5 | 27.0 | 20.0 | 26.0 | 12.0 |
| 27.0 | 22.0 | 27.5 | 24.5 | 27.2 | 21.2 |
| 28.0 | 21.0 | 20.0 | 29.5 | 24.0 | 18.0 |
| 25.5 | 22.5 | 21.0 | 24.5 | 25.5 | 23.5 |
| 23.0 | 20.5 | 14.0 | 20.0 | 26.0 | 20.5 |
| 28.5 | 31.7 | 22.7 | 19.0 | 21.0 | 22.0 |
| 32.0 | 24.0 | 13.0 | 17.0 | 25.0 | 20.5 |
| 27.0 | 26.5 | 24.0 | 12.5 | 22.5 | 18.0 |
| 27.0 | 26.0 | 20.5 | 8.5 | 17.0 | 17.5 |
| 24.0 | 29.5 | 28.0 | 26.0 | 20.5 | 18.7 |
| 27.5 | 27.0 | 27.0 | 17.5 | 21.5 | 16.5 |
| 27.7 | 29.5 | 35.7 | 19.0 | 20.0 | 16.7 |
| 28.5 | 28.5 | 32.0 | 19.0 | 14.0 | 21.0 |
| 17.0 | 29.0 | 30.0 | 22.0 | 19.0 | 21.0 |
| 26.5 | 20.5 | 20.2 | 17.2 | 23.0 | 12.5 |
| 27.0 | 26.0 | 21.0 | 20.0 | 16.2 | 10.2 |
| 25.0 | 22.5 | 29.2 | 20.5 | 17.7 | 16.0 |
| 18.5 | 25.5 | 29.0 | 27.0 | 22.0 | 20.0 |
| 22.5 | 28.2 | 28.0 | 19.5 | 18.0 | 19.0 |
| 25.5 | 31.0 | 27.0 | 22.5 | 23.5 | 18.0 |
| 23.0 | 26.2 | 24.0 | 23.0 | 25.0 | 24.0 |
| 22.5 | 28.0 | 23.0 | 25.0 | 26.5 | 26.0 |
| 28.0 | 34.7 | 20.0 | 24.7 | 21.7 | 15.0 |
| 24.0 | 33.0 | 28.0 | 24.0 | 18.0 | 18.5 |
| 20.0 | 26.0 | 22.7 | 23.0 | 20.0 | 19.5 |
| 20.2 | 33.5 | 19.0 | 20.0 | 19.0 | 16.0 |
| 24.2 | 23.0 | 16.7 | 21.0 | 21.0 | 20.0 |
| 28.0 | 33.5 | 16.5 | 21.0 | 19.5 | 22.7 |
| 20.7 | 34.0 | 18.0 | 23.5 | 20.7 | 20.0 |
| 21.0 | 28.0 | 18.5 | 23.0 | 22.0 | 18.5 |
| 27.0 | 27.0 | 18.0 | 23.7 | 20.2 | 20.7 |
| 26.5 | 28.0 | 19.5 | 22.0 | 17.0 | 20.0 |
| 22.0 | 29.7 | 19.5 | 26.0 | 18.0 | 26.5 |
| 26.0 | 38.0 | 18.5 | 20.0 | 25.0 | 27.2 |

In 1909 Mr. E. G. McCloskey, who was at that time a student at Cornell, harvested potatoes on a piece of apparently uniform land in a potato field. He harvested each row in six sections, each of which was seventy-two feet and seven inches long. There were thirty-four rows, the space between rows being thirty-four inches. The tubers from each section of each row were weighed as removed from the ground. I have taken the liberty of using Mr. McCloskey's data from this field but have discarded the sections at the ends of all rows as the material when including these sections failed to give a satisfactory frequency curve, while by discarding these the curve indicates a fairly homogeneous material. Owing to the fact that there is a marked falling off in productiveness from section *B* to section *E*, inclusive, the entire row must be used in working the material, and plats of less than 1/50 acre cannot be used. The yields in pounds are given in Table III.

A row of potatoes from section *B* to section *E* inclusive constitutes about one fiftieth of an acre. By increasing the number of rows in a plat the area may be increased at will. Using this means of obtaining plats of different sizes and calculating the probable error by the same method as that previously used we find the following:

| Size of Plat. | Probable Error. Per Cent. |
|---|---|
| 1/50 acre | 6.1 |
| 1/25 acre | 4.8 |
| 2/25 acre | 3.8 |
| 3/25 acre | 3.2 |
| 4/25 acre | 3.3 |

There is in this field no very great increase in the probable error until the plats become as small as one twenty-fifth of an acre.

Mercer and Hall[3] conclude from experiments with small sections harvested from a field of mangolds and also from a field of wheat that the decrease in the probable error is slight when the plats are made larger than one fiftieth of an acre.

Wood and Stratton,[4] as the result of somewhat similar calculations involving a large number of plats, state that the probable error is not larger for plats of one eightieth acre area than for large plats up to one fourth acre in size.

There appears to be much in favor of the use of small plats for field experiments. If they approximate in accuracy the larger plats there remains the possibility of reducing the error still lower by repeating the same treatment on several small plats, a precaution that is not so easily taken with large plats on account of the area of land involved. The greater care that can be given to cultural operations on small plats, and the greater accuracy that is possible in sampling

[3] Mercer, W. B., and Hall, A. D. The experimental error of field trials. Jour. Agr. Science 4: 107–132, 1911.

[4] Wood, T. B., and Stratton, F. J. M. The interpretation of experimental results. Jour. Agr. Science 3: 417–440.

both the crop grown upon them, and the soil composing them are practical considerations which recommend the use of small plats to the professional experimentalist. For the farmer, or for cooperative experiments with farmers, they are probably too delicate an instrument.

### *Size of Plat in Relation to Individuality of Plants.*

When the yield from a small number of plants is used as a measure of differences in plats there may be an error caused by a greater or less growth in certain plants due not to the treatment, but to the inherent property of certain individuals. The probable error arising from this cause is self-evidently decreased with an increased number of plants. How large the number may be that is required to eliminate the difficulty has not been worked out. The writer conducted an experiment in 1910 in which maize from the same ears was planted on certain plats and from a mixture of ears on other plats. The results, which were reported to this Society,[5] showed practically no difference on plats on which the number of plants was about one hundred. The same kind of an experiment was conducted in 1911 on plats of the same size.

The probable error for any plat of the nineteen (plats 1,601–19) planted with seed from the same ears was 6.0 percent, while that for any plat of the thirty-seven (plats 1,201–37) planted with mixed seed was 5.2 percent. The experiments of the two years indicate that a plat having an area of one hundredth acre and growing a hundred maize plants is large enough to eliminate errors due to ordinary variations in the productiveness of individual plants, at least so far as it can be estimated by the method used.

### *Size of Plat in Relation to Sampling.*

Another advantage in the small plat for experiments dealing with soil is the probability of securing a more representative sample of soil where the area to be sampled is small. Experiments conducted by Kaserer[6] led him to conclude that a sample must be taken from every square meter if it is to be representative of the soil. Where samples are taken frequently, as is sometimes done for moisture or nitrate determinations, the number of borings required on a large plat would make sampling exceedingly laborious, if representative samples were secured.

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[5] Lyon, T. Lyttleton. A test of planting plats with the same ears of corn to secure greater uniformity in yield. Proc. Am. Soc. Agron. 2: 35–37 (1910), 1911.

[6] Kaserer, H. A contribution to the question of the determination of the plant food content of a soil plat. Zeitschrift Landw. Versuchswesen f. Oesterreich 13: 742–747, 1910.

### *Shape of Plats.*

The long, narrow plat has generally been considered the most desirable shape. This is apparently open to question, especially if no check plats are used.

Comparing plats in the series 1,201–1,238 previously described, we find that the plats ten feet wide used singly show a probable error of 3.6 percent when every other plat is a check, while with the same arrangement of check plats, when the plats are double width, the probable error is 5.4 percent. When the calculations were made without the use of check plats there was practically no difference in the probable error. This indicates that when check plats are used there is an advantage in having long, narrow plats, but when no checks are used the shape of the plat is not of so much importance.

Mercer and Hall[7] in grouping small plats secured by harvesting rows of mangels in sections, found that there was no advantage to be gained from the use of long, narrow plats over square ones of the same area. They also harvested an area of one acre from a wheat field in five hundred separate plats of equal size. The data from the wheat field they did not use for comparing plats of different shapes. I have grouped these small plats from the wheat field into units of twenty-five, each unit having an area of one twentieth acre. In one system of units the one twentieth acre plats extend from one side of the field to the other, having the width of eleven rows of the drill. A very long, narrow plat is thus formed. The other unit has dimensions of five plats each way, which gives the same area as the other with a shape approaching a square. Using the total yields of grain and straw on these units, the probable error for the long and narrow plats is 2.3 percent and for the more nearly square plats is 4.8 percent. When check plats are used every third plat, in a manner to be described later, the calculated error for the long narrow plats is 1.8 percent and for the others is 3.2 percent. In this case the long, narrow plats possessed as great an advantage when no checks were used as when they were.

It should also be stated that calculating the probable error for the small plats in the mangel field, referred to above, there was no reduction of the error for the long plats as compared with the square ones when checks were introduced every third plat.

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[7] Mercer, W. B., and Hall, A. D., loc. cit.

It would seem reasonable to suppose that when check plats are used there would be an advantage from the use of long, narrow plats as compared with square ones of the same area. The narrow plats bring the check plats closer together and, as evidence to be shown later strongly indicates that the more frequently the check plats occur in a series the less the probable error for any test plat, there should be a corresponding reduction of error when the checks are brought nearer one another by decreasing the width of the plats. More data are required before any conclusion can safely be drawn on this subject.

### *Use of Check Plats.*

It is quite customary now to use check plats at more or less frequent intervals among the test plats. The insertion of a check plat every third plat is the most abundant use of the check plat that has come to my attention. There is always a temptation to increase the number of test plats and minimize the number of check plats, the result being that few experimenters use many checks.

The assumption upon which the use of the check plat is based is that the productiveness of the soil changes gradually from point to point and that consequently the natural productive capacity of any plat may be determined by its distance from two plats on either side, the natural productive capacities of which are known. This may or may not be true. The nearer together the check plats the more likely it is to be the case, which is at once an argument in favor of frequent checks and narrow plats.

The experiments at the Nebraska Station, already cited, in which three rows of eight plats each were cropped in the same way for from four to seven years, show that it is not always possible to determine the productive capacity of a plat two rods wide even when every other plat is a check.

It is quite evident from these figures that it would be impossible to predict the productive capacity of many of these plats even when the yields of the two immediately adjacent plats are known. In most cases the two or three most productive plats lie side by side, but it is also true that radical changes occur on contiguous plats, as for instance, plats 61 and 62, and plats 76, 77 and 78.

### *Correcting Results by Means of Check Plats.*

There are three possible ways of calculating increased or decreased effect of treatment or crop on plats lying between checks. These are illustrated in Table IV.

Table IV.—*Methods for Correcting from Check Plats.*

| Plat No. | Actual Yield. Bu. | Normal Yield. Bu. | Increase or Decrease Based on: | | |
|---|---|---|---|---|---|
| | | | Yield for Nearest Checks. Bu. | Yield for Nearest Checks. Percent. | Average for All Checks. Bu. |
| 1 (check).... | 70 | 70 | | | |
| 2 .......... | 70 | 65 | 5.0 | 7.7 | 10.0 |
| 3 .......... | 64.8 | 60 | 4.8 | 8.0 | 4.8 |
| 4 (check).... | 55 | 55 | | | |
| 5 .......... | .. | | | | |
| 6 .......... | .. | | | | |
| 7 (check).... | 55 | 55 | | | |

In Table IV the column of actual yields gives the harvest yields from both check and test plats in bushels or pounds as the case may be. As the yields for plats 5 and 6 are not needed for the illustration these are not given. The normal or theoretical yields for the test plats are based on the supposition that the soil lying between the check plats gradually changes in productivity in a perfectly uniform manner; hence plat 2 yields less than plat 1 by one third of the difference between plat 1 and plat 4, and plat 3 less by two thirds of the difference. It plat 4 had yielded more than plat 1 the increase for plats 2 and 3 would have been at the same rate.

The increase or decrease in yield due to the treatment given the test plat is then found by subtracting the normal yield from the actual yield. This may be expressed in bushels or pounds or in percentage. The latter is determined by dividing the increase or decrease in bushels by the normal yield for the plat. In the illustration used it will be seen that while the increase in bushels is greater for plat 2 than for plat 3 the reverse is the case when calculated in percentage. The statement in percentage offers without doubt, a more accurate method of judging the relative effectiveness of two or more kinds of treatments when considerable variation occurs in the productivity of the plats.

The last column in Table IV shows the increase or decrease obtained by comparing the actual yield of a plat with the average yield of all check plats. If the field should be very uniform or if the number of check plats should be very great this method would give satisfactory results, but its accuracy decreases with a decrease in either of these conditions. It is mentioned merely because it is sometimes used.

In calculations by the writer of probable error for any series of plats in which checks are used the deviations of the test plats from the normal expressed in percentage, as shown in the next to the last column in Table IV, are squared, the sum of the squares divided by the number of test plats minus one, and the square root of this product multiplied by 0.67. In other words the percentage deviation from the normal is substituted for the percentage deviation from the mean.

### *Use of Check Plats to Reduce Experimental Error.*

Like the other factors influencing the accuracy of field plat tests the use of check plats requires experimentation on numerous soils and under many conditions. The method of least squares has not yet been applied to this phase of the subject, but two experimenters report conclusions based on the average deviation of the test plats from the normal.

Morgan,[8] working on the experiment field at Cornell, found that the error for a series of similarly treated plats planted to wheat and afterwards to maize decreased uniformly as the distance between check plats decreased, when the 10th, 5th, 3d and 2d plats respectively were used as checks.

McCloskey[9] as the result of careful harvesting of potatoes grown in three fields in New York State concluded that the number and distance apart of check plats made no difference.

Calculations based on different arrangements of the one hundredth acre plats already referred to indicate that the frequency of occurrence of the check plats make a great difference in the accuracy of field experiments.

When every other plat is used as a check in the series of plats 1,201–1,237 the probable error is 3.6 percent; every fourth plat a check, p. e. = 5.3 percent; every sixth plat a check p. e. = 5.5 percent and no checks, p. e. = 5.2 percent.

Recalculating the data obtained by Morgan from the wheat crop on plats 2,051–2,146 by means of the method described above we find that when every other plat is a check p. e. = 4.0 percent; every third plat a check p. e. = 5.0 percent; every fourth plat a check p. e. = 5.7 percent; every 6th plat a check p. e. = 5.3 percent.

The greater accuracy obtainable when check plats are used may also be shown by using one twentieth acre plats from the wheat field harvested by Mercer and Hall. When the square plats are used without checks the p. e. = 4.8 percent; with checks every third plat p. e. = 3.2 percent. For the long, narrow plats without checks p. e. = 2.3 percent; with checks every third plat p. e. = 1.8 percent.

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[8] Morgan, J. O. Some experiments to determine the uniformity of certain plats for field experiments. Proc. Am. Soc. Agron. 1: 58–67 (1908–09), 1910.

[9] McCloskey, E. G. Methods of the laying out of field experiments. Thesis for degree of B.S.A., Cornell University, pp. 37, 1909.

Recapitulating these calculations in tabular form we have:

TABLE V.—*Probable Error for any Plat When Check Plats are Located at Different Intervals and When No Checks are Used.*

|  | Plats 1,201–1,237. Percent. | Plats 2,051–2,146. Percent. | Mercer & Hall Wheat Field. |  |
|---|---|---|---|---|
|  |  |  | Square Plate, Percent. | Long Plats, Percent. |
| Check every 2d plat........ | 3.6 | 4.0 |  |  |
| Check every 3d plat........ |  | 5.0 | 3.2 | 1.8 |
| Check every 4th plat....... | 5.3 | 5.7 |  | 2.6 |
| Check every 6th plat....... | 5.5 | 5.3 |  |  |
| No checks................. | 5.2 |  | 4.8 | 2.3 |

There can be no doubt that the use of checks every second or third plat allows of greater accuracy than when no checks are used, but the data at hand do not indicate any advantage from the use of check plats at less frequent intervals.

## *Distribution of Test Plats.*

As has already been stated, one of the advantages to be gained from the use of small plats is to be found in the ease with which tests may be replicated. The repetition of each test may, moreover, be made on widely separated plats in the series, which will nearly always result in securing somewhat different soil conditions. In Fig. 3 the widest possible distribution of each test has been attempted, and it will serve as an example of distributed test plats in the comparison which follows.

Let is suppose the two rows of plats containing the series 1,201–1,234, 1,401–1,434 to be so arranged that checks occur every fourth plat except on one end of each row where there is an extra check interposed in order to alternate the checks in the rows, and let us consider each test to be repeated four times and to be distributed as widely as possible, thus giving twelve tests. Calculated on this basis the probable error for any treatment is 2.0 percent.

In order to compare the arrangement of plats described above with a system in which the test plats are not distributed, but in which the same area of land is devoted to each test, we may imagine a disposition of the plats such as that shown in Fig. 4. In this system the two adjoining plats in each row are combined with the two corresponding plats in the opposite row. Check plats representing the same combination are interposed every fourth combination. The probable error for any test in this arrangement is 4.5 percent.

It will thus be seen that by distributing the one twenty-fifth acre devoted to any test in four widely separated plats a much greater degree of accuracy is secured than where the same area of land in one body is used for the test.

### Some Possible Sources of Error in Variety Testing.

Granting that variety testing has a useful mission in field crop experimentation, it becomes important to guard against the errors that may interfere with the accuracy of such tests. The sources of error which my data will permit me to discuss are the following:

1. Influence of previous environment of the varieties tested.
2. Influence of season.
3. Method of drawing conclusions.

### *Influence of Previous Environment.*

This possible source of error having received the least attention of any, I shall discuss it first and somewhat more at length than the others. That it is always a difficulty I do not claim, but I shall endeavor to show that under some circumstances it may be of so much importance as to completely nullify the value of the experiments.

The manner in which the previous environment of the variety affects its relative productiveness is through the adaptation of the variety to the conditions under which it was previously grown and the degree to which this affects its ability to adapt itself to its new surroundings. For instance, seed of one of the varieties to be tested, which we shall call *A*, if previously grown for one or more years in a region having different climatic or soil conditions may have acquired habits of growth that will cause it to yield less than another variety, *B*, the seed of which had been grown under conditions more similar to those under which the test is made, but if both varieties had been raised under the same conditions *A* might have yielded more than *B*.

As this is a condition not generally realized some experimental evidence should be offered to show its actuality.

There must of course, be some reason for this, and although my purpose is to call attention to the phenomenon as affecting the accuracy of variety testing yet a comprehensive treatment of the subject requires that some explanation be given.

Such explanation is to be found in the quality that plants possess of adapting themselves to a new environment through such modifications in their form, structure or habits of growth as may better enable them to perpetuate themselves under the new conditions. In this way a variety brought from one region to another will frequently yield better the second year it is grown in the new locality than it did the first year and possibly keep improving for several years thereafter. The effect on its productiveness will be greater the more radical the change in the climatic and soil conditions. My observation of this effect has been gained in a region of semi-aridity into which plants were brought from humid conditions. Under these circumstances the modifications were very pronounced.

I shall cite two experiments showing the modifications which occur in bringing varieties of corn and wheat from a humid to a semi-arid region.

## *Experiments Showing that Modifications Occur in Plants when Carried from one Environment to Another.*

Seed of two varieties of maize, Snowflake White and Early Yellow Rose, was obtained from Shenandoah in western Iowa and grown two years in central Nebraska. It was then planted at the Experiment Station in eastern Nebraska beside the same varieties, the seed of which had been obtained from the crop grown at Shenandoah the previous year. In this way seed of the same varieties, grown in the one case in Iowa continuously, and in the other in central Nebraska for two years, were tested under the same conditions, consequently if any change had taken place in the habits of growth of the variety during its residence in Nebraska the modification could be detected.

The following table shows the difference in the Iowa and Nebraska plants. The dimensions and weights of plants were obtained by measuring and weighing ten plants from each plot. The yields per acre were obtained from the entire plat:

TABLE VI.—*Modifications Induced in Maize by Its Environment.*

| Data Obtained. | Snowflake White. | | Early Yellow Rose. | |
|---|---|---|---|---|
| | Nebraska Seed. | Iowa Seed. | Nebraska Seed. | Iowa Seed. |
| Height of stalk (inches) | 89.2 | 100.3 | 92.9 | 96.2 |
| Height of ear (inches) | 34.7 | 43.5 | 37.7 | 38.7 |
| Length of shank (inches) | 5.5 | 7.4 | 5.3 | 7.4 |
| Number of leaves | 12.5 | 13.7 | 12.6 | 13.0 |
| Number of ear nodes | 6.8 | 7.7 | 6.8 | 7.1 |
| Weight of stalk (grams) | 202.5 | 266.5 | 174.0 | 229.7 |
| Weight of ear (grams) | 269.4 | 303.7 | 238.0 | 235.0 |
| Total weight (grams) | 471.9 | 570.2 | 412.8 | 465.2 |
| Ratio stalk to ear | 1 : 1.33 | 1 : 1.14 | 1 : 1.37 | 1 : 1.02 |
| Leaf area (sq. inches) | 1,066.0 | 1,262.0 | 1,001.0 | 1,035.0 |
| Yield per acre (bushels) | 73.7 | 68.7 | 68.1 | 62.1 |
| Date of tasseling | Aug. 1 | Aug. 6 | Aug. 2 | Aug. 4 |

The most marked changes are in the Snowflake White variety, where as the result of two years growth in central Nebraska, the stalk has decreased almost a foot in height, the ear is 8.8 inches lower down on the stalk, and the shank almost two inches shorter, while the plants have an average of 1.2 fewer leaves.

The weight of the stalk is heavier in the plants grown from the Iowa seed, and the ear on the Snowflake White is heavier, but on the Early Yellow Rose the Nebraska seed produced a slightly heavier ear. The proportion of the ear to the total weight of the plant is much higher in the Nebraska maize. It is also significant that the Nebraska plants have an average of almost 100 square inches less leaf surface. Plants growing in a drier climate usually have less leaf area than those growing under more humid conditions. The yield of grain was greater from Nebraska seed.

An experiment giving similar results was conducted with wheat. Turkey Red wheat seed was obtained from the Ohio Experiment Station in eastern Ohio and the Iowa Station in central Iowa, while through the Kansas Station was obtained a sample from central Kansas. These samples and one of Turkey Red wheat that had been grown at the Nebraska Station for three years were sown on contiguous plats of land. The record of growth shows great differences in the habits of these four strains of what was, without doubt, originally the same wheat. That the Nebraska and Iowa were originally the same is certain, for the Nebraska seed had been obtained from the Iowa Station three years before. The Ohio seed had been raised there only one year and probably came from the Iowa Station.

TABLE VII.—*Modifications Induced in Turkey Red Wheat by Its Environment.*

| | Kansas Seed. | Nebraska Seed. | Iowa Seed. | Ohio Seed. |
|---|---|---|---|---|
| Date of sowing | Sept. 9 | Sept. 9 | Sept. 9 | Sept. 9 |
| Stand in fall | Good | Good | Good | Good |
| Stand in spring | Good | Good | Good | Good |
| Lodged | None | None | Badly | Badly |
| Rust | Very little | Very little | Much | Much |
| Date of ripening | June 25 | June 27 | July 2 | July 3 |
| Yield of grain per acre | 29.1 bu. | 27.5 bu. | 22.3 bu. | 23.1 bu. |
| Weight of grain per bu. | 64.2 lb. | 62.2 lb. | 56.9 lb. | 58.9 lb. |

The winter of 1899–1900 was a very favorable one for winter wheat and a comparison of the stand in the fall and spring showed that there was no appreciable loss from winter killing.

The differences in the habits of growth of these wheats were very marked. During the fall and early spring the Kansas and Nebraska wheats were quite similar, but differed from the Iowa and Ohio wheats in being shorter, stooling more, lying closer to the ground, and presenting a dark green color. The stands of all were about the same. Before harvest the Iowa and Ohio plants had made a ranker growth than those from Nebraska and Kansas seed, they were also more badly affected by rust and had lodged to some extent, while the others had not lodged at all. There was a marked variation in the time of ripening, the Nebraska wheat being two days later than the Kansas, the Iowa wheat five days later than the Nebraska and the Ohio one day later than the Iowa wheat. The quality of early maturity is so important in Kansas and southern Nebraska because of the intensely hot, dry weather of midsummer that wheats that have not acquired this property suffer accordingly in yield. These wheats when afterwards grown in Nebraska for a number of years finally differed in no way from the original Nebraska wheat. For instance, in 1903 the yields of all except the original Ohio wheat and of several others brought to Nebraska in 1902 and thus grown one generation in Nebraska were as follows:

Table VIII.—*Turkey Red Wheat Tested at the Nebraska Station in 1903.*

| Source of Seed. | Yield per Acre. |
|---|---|
| Grown continuously at Station | 31.8 |
| Grown in western Kansas until 1902 | 31.1 |
| Grown in eastern Kansas until 1902 | 29.6 |
| Grown in eastern Kansas until 1899 | 31.3 |
| Grown in Iowa until 1902 | 27.3 |
| Grown in Iowa until 1899 | 31.6 |
| Grown in Ohio until 1902 | 28.1 |

This table shows that the importations of 1899 yielded as well as the original Nebraska wheat by 1903, but that the later importations had not yet become adapted to the locality. It is quite evident that these would have made a poor showing the first year in a variety test, and a very valuable variety might thus have been lost.

A number of other varieties of Nebraska-grown wheats growing in 1900 show less difference between varieties in yield and habits of growth than did these samples of the same variety from different States during the first year of their test.

Similar results have been obtained in testing varieties for hardiness. In the winter of 1896–7 among a number of winter wheats tested were samples of Turkey Red from Iowa and Kansas. The Iowa wheat survived the winter creditably, although somewhat injured, yielding at the rate of twelve bushels of grain per acre. The Kansas wheat was completely destroyed.

Again in the winter of 1898–9, Turkey Red wheat raised two or three years in Kansas, but previously in Missouri, was being tested with the same variety originally from Kansas, but having been grown for an unknown length of time in Iowa and later for two years in Nebraska. The Kansas-Missouri wheat was completely winter-killed, while the Iowa-Nebraska wheat yielded 23.5 bushels of grain per acre.

It would seem from these results that the habits of growth of the wheat and maize plants are very readily changed by their environment, and that a very few years are sufficient to produce a great difference in this respect which becomes apparent when the plants are brought under new conditions; that while certain variety characteristics undergo slight changes, others, frequently those upon which its productiveness or hardiness may depend, are deeply affected.

Table IX.—*Showing the Effect on Its Productiveness of the Locality in Which Seed is Raised.*

| Variety. | Source of Seed. | Yield per Acre in Bushels. | | | | Differences in Favor or Disfavor of Adapted Seed. |
|---|---|---|---|---|---|---|
| | | 1903. | 1904. | 1905. | Average. | |
| Silver Mine | Saline Co., Neb. | | 70.0 | 76.1 | 73.0 | |
| | Illinois, | | 65.1 | 63.4 | 64.2 | + 8.8 |
| Snowflake White | Lancaster Co., Neb. | | 84.8 | 74.5 | 79.6 | |
| | Iowa | | 72.8 | 67.1 | 69.9 | + 9.7 |
| Early Yellow Rose | Saline Co., Neb. | | 67.9 | 75.1 | 71.5 | |
| | Iowa | | 76.9 | 65.5 | 71.2 | + .3 |
| Reid's Yellow Dent | Pawnee Co., Neb. | | 87.1 | 63.4 | 75.2 | |
| | Illinois | | 82.8 | 60.8 | 71.8 | + 3.4 |
| Reid's Yellow Dent | Neb. Experiment Sta. | | 79.5 | 65.0 | 72.2 | |
| | Illinois | | 82.8 | 60.8 | 71.8 | + .4 |
| Silver Mine | Saline Co., Neb. | | | 76.1 | 76.1 | |
| | Illinois | | | 63.4 | 63.4 | +12.7 |
| Snowflake White | York Co., Neb. | 73.7 | | | 73.7 | |
| | Iowa | 68.7 | | | 68.7 | + 5.0 |
| Early Yellow Rose | York Co., Neb. | 68.0 | | | 68.0 | |
| | | 62.0 | | | 62.0 | + 6.0 |
| Leaming | Buffalo Co., Neb. | | 95.2 | 69.8 | 82.5 | |
| | Illinois | | 76.6 | 72.3 | 74.4 | + 8.1 |
| Boone County White | Otoe Co., Neb. | | 76.2 | | 76.2 | |
| | Illinois | | 68.9 | | 68.9 | + 7.3 |
| Silver Mine | Washington Co., Neb. | | | 61.3 | 61.3 | |
| | Illinois | | | 63.4 | 63.4 | − 2.1 |
| Nebraska White Prize | Saline Co., Neb. | | 89.2 | 79.0 | 84.1 | |
| | Washington Co., Neb. | | 82.1 | 79.0 | 80.5 | + 3.6 |
| Hogue's Yellow Dent | Neb. Experiment Sta. | | | 67.6 | 67.6 | |
| | Saline Co., Neb. | | | 65.0 | 65.0 | + 2.6 |
| Nebraska White Prize | Saline Co., Neb. | | | 79.0 | 79.0 | |
| | Washington Co., Neb. | | | 63.4 | 63.4 | + 5.6 |
| Silver Mine | Saline Co., Neb. | | | 76.1 | 76.1 | |
| | Washington Co., Neb. | | | 61.3 | 61.3 | +14.8 |
| Iowa Gold Mine | Buffalo Co., Neb. | 61.5 | | | 61.5 | |
| | Washington Co., Neb. | 60.9 | | | 60.9 | + .6 |

While these examples are drawn from experiments in which plants are brought from a humid to a semi-arid region it cannot be said that the effect is confined to such conditions. A change from north to south is undoubtedly accompanied by a similar phenomenon. Of this Professor J. F. Duggar says:[10]

"Corn brought south from higher latitudes becomes later and later each year for several years after its introduction, the plant grows taller, and generally the proportion of trashy weavil-eaten or otherwise unmarketable grain becomes less than during the first year of growth in the south."

To be sure there is not much experimental data on this subject, and frequently the error is slight, but it is a real one, and in some cases may be very large, consequently precautions should be taken against it. Reliable conclusions cannot be drawn when varieties are collected from regions differing in their climatic conditions, and tested for a year or two, or indeed for any length of time, if the seed is each year obtained from a foreign source. Each variety must be grown for a number of years in the region in which it is to be tested in a similar environment until it has undergone the changes incident to adaptation to its new environment. It is only after such adaptation has taken place that its real value in any locality can be determined.

Table IX shows the almost uniformly better yields of maize raised from locally grown seed as compared with seed from a distance.

### *Influence of Season.*

The character of the season in which the test is made may affect the results through the natural ability of a certain variety to withstand drought or excessive moisture, or to flourish under excessive heat or continued low temperature. This can be remedied by extending the test over a number of seasons, so as to find the variety that thrives best in an average season. As a number of unusual seasons sometimes occur consecutively it is evident that the test should extend over a period of from five to ten years.

The following taken from a variety test at the Nebraska Experiment Station is an illustration of the effect of a moderately dry season in depressing to a greater extent the yields of large-eared varieties of maize than of small-eared varieties. It should also be explained that the large-eared varieties are grown in the Missouri River valley, while the others are raised about sixty miles west of it.

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[10] Duggar, J. F. Corn culture. Alabama Exp. Sta. Bul. 134: 171–203, 1905.

TABLE X.—*Showing the Influence of Rainfall in Determining Whether a Large-ear or a Medium-ear Variety of Maize Produced the Larger Yield.*

| Variety. | Size of Ear. | 1904. | 1905. | 1906. | 1907. | Average. | Below Av. in 1906. |
|---|---|---|---|---|---|---|---|
| Reid's Yellow Dent | Medium | 70.9 | 59.4 | 51.2 | 64.1 | 61.4 | 10.2 |
| Mammoth White Pearl | Large | 72.5 | 69.4 | 44.8 | 65.7 | 63.1 | 18.3 |
| Hogue's Yellow Dent | Medium | 71.2 | 60.0 | 51.7 | 63.7 | 61.9 | 10.2 |
| Mammoth Golden Yellow | Large | 67.6 | 65.7 | 44.6 | 61.3 | 59.8 | 15.2 |
| Rainfall, departure from normal May–August. Inches |  | .42 | 2.55 | —.97 | 1.12 |  |  |

In this experiment there were two large-eared varieties of maize and two varieties with medium-sized ears. They were grown side by side for a number of years, the seed of each being obtained from the same source. It will be seen in Table X that in years when the summer rainfall was large the large-ear varieties produced the better; this was notable in 1905. In 1907 when the rainfall was less the large-ear varieties produced relatively less well, while in 1906 when the rainfall was nearly an inch below the normal the large-ear varieties yielded much less than the varieties having medium-sized ears.

These relationships are shown graphically in Fig. 5. In this diagram the total rainfall, normal and actual, for the period May to August inclusive is shown by the lines above the lines for yields of maize. The normal and actual rainfall by months for the same periods are shown below, as are also the temperatures by months. The yields of the large-ear varieties evidently follow the rainfall much more closely than do the other varieties. Temperature does not vary sufficiently to make much difference, and, although the distribution of the rainfall by months varies considerably in the different years, it is apparently the total quantity which fell during the period from May to August inclusive that determined the relative yields of the types of maize under experimentation.

The danger of drawing conclusions from variety tests conducted through a single season thus becomes apparent, and, as a series of wet or dry seasons frequently continues for several years, the study of weather conditions in connection with variety tests is evidently important.

## *Method of Drawing Conclusions From Variety Tests.*

There are two ways in which varieties may be ranked in productiveness after they have been tested a number of years. (1) By averaging the yields for all of the years tested and basing the relative standing upon the average yield. (2) By grading the varieties for each year and basing the relative standing on the average rank. Take, for instance, the hypothetical case presented in Table XI.

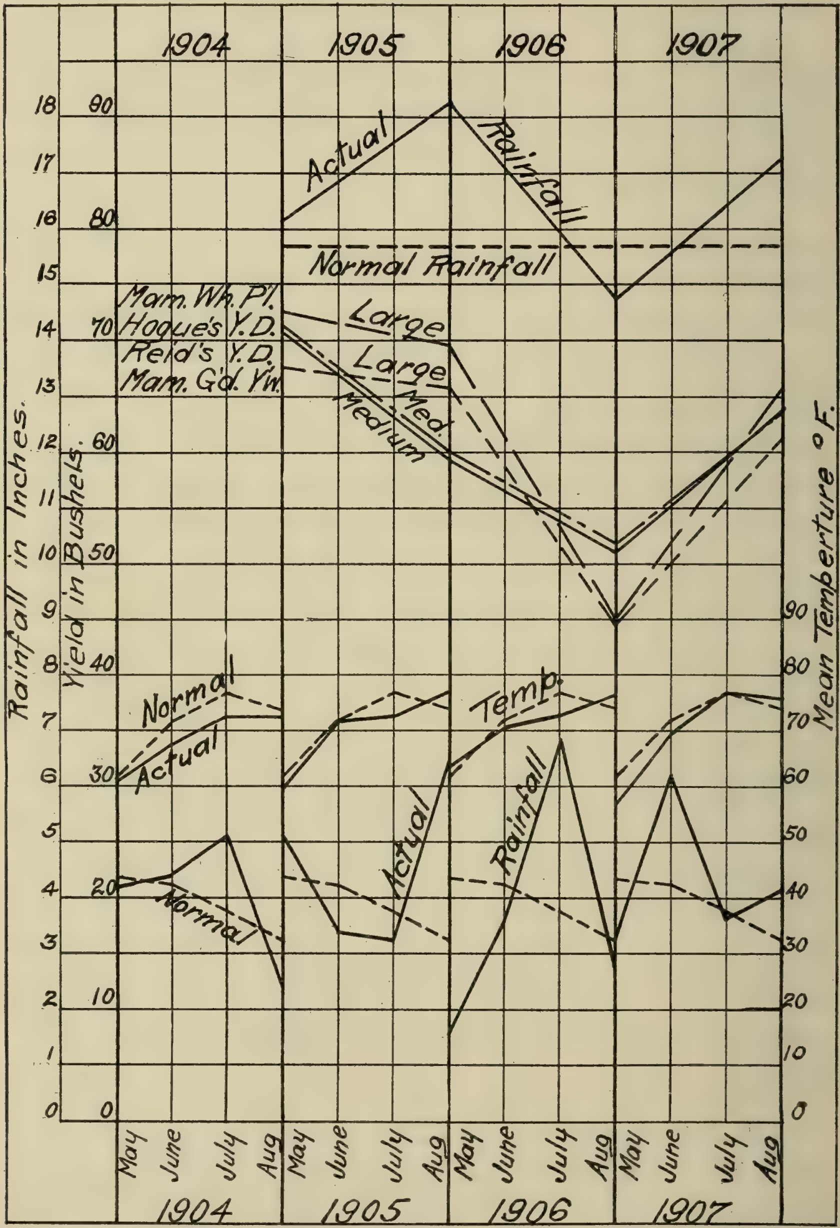

FIG. 5.—Influence of rainfall on the relative yields of large ear and medium ear varieties of corn.

TABLE XI.—*Methods of Grading Varieties.*

| Variety. | 1903. | | 1904. | | 1905. | | Average Yield. | Rank by Yield. | Rank Based on Average Rank. |
|---|---|---|---|---|---|---|---|---|---|
| | Yield. | Rank. | Yield. | Rank. | Yield. | Rank. | | | |
| *A* | 45 | 1 | 40 | 1 | 60 | 2 | 48⅓ | 2 | 1 |
| *B* | 37 | 3 | 36 | 3 | 56 | 3 | 43 | 4 | 3 |
| *C* | 42 | 2 | 38 | 2 | 70 | 1 | 50 | 1 | 2 |
| *D* | | | | | 47 | 4 | 47 | 3 | 4 |

Variety *C* ranks first in average yield, but when graded according to average rank variety *A* stands first. This is owing to the fact that in a year favorable to high yields *C* yielded considerably higher than *A*, but in less favorable years *A* showed greater ability to withstand drought or other untoward conditions and yielded more. Doubtless the variety which produces the most in a series of years is the most desirable, which being the case the rank according to average yield appears to be the most satisfactory method.

Variety *D* was tested only one year. If *D* had increased in 1905 proportionally to *C*, it would if tested in 1904 have yielded only 25 bushels. It is evidently then a less productive variety than *B*, but if ranked according to average yield would stand higher. An error would, therefore, be introduced if average yield were taken as the basis for measurement in this case, and the liability to serious error would be greater than would be likely or even possible were the relative productiveness based upon rank.

I would suggest the following rule to govern the rating of varieties in a test. When all varieties have been tested during the same long period the average yield should be taken as the basis for comparison. When it is necessary to compare varieties of which one or more have been tested for only a few seasons while others have been tested for a length of time sufficient to give satisfactory results, or when all have been tested only a short time, the average rank for each year shall serve as the basis on which relative yields are tentatively based.

## ACKNOWLEDGMENTS.

I wish to express my indebtedness to Dr. H. H. Love, of Cornell University, for much advice and assistance in preparing this paper; also to the investigators whose data I have used to supplement my own too meager supply.

## SUMMARY.

Final conclusions regarding the conditions most favorable to the accurate conduct of field experiments will require a very large amount of data and this must be collected at a large number of places, but the record of data with its indications should be made available to experimenters as collected.

Yield records of twenty-four plats of one twentieth acre each during the period 1900–1907, when the plats all received the same treatment, indicates that it is not possible to establish a schedule of relative yields for a series of plats, even after several years comparison.

There seems to be little gained in accuracy by using plats larger than one fiftieth of an acre in size, when the yield of crop is made the criterion. For accuracy in sampling soil the smaller the plat the better. When it is possible to give small plats careful treatment, and to repeat each treatment several times the small plats are to be preferred to large ones.

Probably one hundred plants on a plat are sufficient to prevent errors due to variations in the productiveness of individual plants.

There is not satisfactory evidence that long and narrow plats are less liable to error than square plats when no check plats are used, but when checks are placed every second or third plat in the series the evidence is in favor of the long and narrow plats.

The use of check plats every second or third plat secures greater accuracy than when no checks are used, but the data at hand do not indicate any advantage from the use of check plats at less frequent intervals.

An area of one twenty-fifth acre of land, in four widely separated plats, devoted to any one test, secures a much greater degree of accuracy than the same area of land in one body.

In some cases seed of varieties grown in a region having climatic conditions different from that in which a variety test is made produces plants which yield much less than would the same varieties if grown for a number of years in the region in which the test was made. The plants need several generations of growth in the new environment to become adapted to it, and in the meantime are likely to give misleading results in a variety test.

The character of the season in which a variety test is conducted may affect the results through the ability of a certain variety to withstand drought or excessive moisture, or to flourish under excessive heat or continued low temperature. The dependence of certain varieties on an abnormally large rainfall is shown.

One variety of plant may be less productive than another, but, if valuated according to average yield, might stand higher if both had not been tested for the same number of years. Under such conditions a valuation based on average relative rank is a more accurate method.

# THE DEVELOPMENT OF SOIL SURVEY WORK IN THE UNITED STATES WITH A BRIEF REFERENCE TO FOREIGN COUNTRIES.[1]

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There is probably no line of agricultural work which has had a more rapid development and extension within the last decade than the classifying and mapping of soils. The work is changing the attitude of investigators toward many problems relating to the soil and is forcing a recognition of the fact that soils possess an individuality just as well as plants and animals. Soil investigators are beginning to realize that a study of the differences, which are observable in the field, and of the numerous agencies and processes to which these owe their existence, is just as essential to a proper understanding of the various properties and characteristics of the soil as are laboratory investigations, and that conclusions drawn from careful field observations are as justly entitled to scientific recognition. For although the laboratory may be the only place where conditions are under control things act differently when this control is removed. An appreciation of this fact is causing greater and greater interest in field studies.

While the soil survey proper has developed in this country practically within the last 15 years much valuable work upon the soils had been done previously and a brief review of some of the more important earlier publications in this as well as foreign countries should be of considerable interest to all soil workers.

The first work upon the soils of this country was conducted principally by geologists. As the soil is composed very largely of mineral matter and has been formed by the breaking down of the rocks, it is but natural that its study, owing to its great economic importance, should have early attracted their attention. Nearly all of the earlier and, in fact, many of the present geological surveys have devoted much of their energies to its study.

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[1] This paper was practically all written more than four years ago as part of a thesis for a degree of Master of Science at the George Washington University. The author had hoped to make it more complete and up to date but this would now necessitate an entire rewriting. As several have expressed a desire for its publication it is here submitted, hoping that it will prove of interest to the members of the Society and stimulate someone else to a better presentation of the subject.—Author. Received for publication Feb. 2, 1912.—Editor.

In a report of A Geological Survey of the County of Albany, taken under the Direction of the Agricultural Society of said County, and published as one of a number of miscellaneous papers in the Memoirs of the Board of Agriculture of the State of New York, Vol. 1, 1820, is given a classification of the soils of Albany County, New York. This report is signed by Amos Eaton and T. Romeyn Beck. In the preliminary observations it is stated that, "The present, so far as it has come to our knowledge, is the first attempt yet made in this country to collect and arrange geological facts with a direct view to the importance of agriculture." The latter part of the report is given over to a discussion of the Alluvial Formations, under which term the authors include all of the soils of the county. "These (alluvial formations) are very naturally divided into the proper unmoved soil, called *'geest,'* and that which has been conveyed from a distance by water and exists in thick beds, called *'alluvion.'* The 'geest' is further divided into five kinds according to the proportion of silex. Analyses were made to determine the amount of silex (sand), 'alumine' (clay), lime, soluble salts, animal and vegetable matter, water, and oxide of iron."[2]

The following shows the classification made:

- Alluvial Formations
  - Alluvion
  - Geest
    - 1. Granulated soil
    - 2. Hardpan
    - 3. Upland loam
    - 4. Upland clay
    - 5. Lowland loam

Eaton followed up his work in Albany County by a geological and agricultural survey of Rensselaer County, New York, in 1822, and of the districts adjoining the Erie Canal in 1824. In these reports he pursued the same lines as in the previous work.

This report upon the soils of Albany County appears, as claimed, to be *the first attempt at classifying the soils of a definite part of this country.* There had been, however, considerable discussion of the subject of soils before this time in some of the textbooks of geology. In the second edition of McClure's Observations on the Geology of the United States, the last two chapters were devoted to a discussion of the weathering of rocks with an inquiry into the effects which they may produce upon the character of the soil, especial attention being given to the physical nature of the resultant soils. Eaton in his Index to the Geology of the Northern States, 1818, had written: "It is agreed by all geologists that all soils, excepting what proceeds from decomposition of animal and vegetable matter, are composed of the broken fragments of disintegrated rock. From this fact it is natural to infer that the soil of any district might be known by the rocks out of which it is formed, . . . but there is great difficulty in determining what rocks may have extended over any particular districts." Of course it is now realized that the difficulty in determining the character of the rocks in the area referred to is due to the influences of glacial action.

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[2] The silex was determined by stirring the soil vigorously in half a pint of pure water for ten minutes, then allowing it to stand for three minutes, after which the liquid was poured off. That which remained was salled "silex," while that which settled from the decanted liquid was called "alumine." Although this was termed chemical analysis, it was really more a physical analysis than a chemical one.

In 1826, Troost made a study of the geology around Philadelphia, and the results of his studies were published under the patronage of the Society for the Promotion of Agriculture. In this paper he discussed with some detail the physical and chemical properties of soils.

In view of the rather heated discussions which are still being waged in regard to the value of chemical analyses of soils, it is interesting to note an article by Eaton (American Journal of Science, XII, June, 1827, p. 370) in which he took the position that the fertility of the soil could not be determined by a chemical analysis. In the second edition of his textbook of geology (1832), "he recognized and emphasized," says Merrill, "a principle now generally accepted, to the effect that the fertility of the soil does not depend upon ultimate chemical constitution but rather upon physical properties; that a fertile soil should contain, first, sufficient stones and pebbles to keep it open and loose; second, sufficient clay to absorb and hold water in the right proportion; and third, sufficient fine sand to keep the clay from baking in time of drought" (Contribution to History of American Geology, Report U. S. National Museum, 1904).

In making a study of any important line of work, it is often difficult to determine to whom the honor of priority belongs, but so far as I have been able to determine the *first map in this country which claimed to show the different character of the soils was that of Massachusetts by Edward Hitchcock, published in 1841.* While this was a geological map, it was claimed by its author that it showed the soils also. "In general," he states in discussing the different kinds of soils, "if any one wishes to recognize them, let him look at the Geological Map that accompanies this report, and he may conclude that the different soils cover those portions of the surface that are represented as occupied by the rocks from which they are derived." The author recognized, however, that the soil material had been moved southward by "diluvial" action, so the soil boundaries and geological boundaries did not always coincide. In his final report he recognized the following varieties and sub-varieties:

1. Alluvium:
    (*a*) From rivers.
    (*b*) Peaty.
2. Diluvium:
    (*a*) Sandy and gravelly.
    (*b*) Argillaceous.
3. Tertiary soil:
    (*a*) Argillaceous.
    (*b*) Sandy.
4. Sandstone soil:
    (*a*) Red.
    (*b*) Gray.
5. Graywacke soil:
    (*a*) Conglomerate.
    (*b*) Slaty, gray.
    (*c*) Slaty, red.
6. Clay slate soil.
7. Limestone soil:
    (*a*) Magnesium.
    (*b*) Common.
8. Mica slate soil.
9. Talcose slate soil.
10. Gneiss soil.
    (*a*) Common.
    (*b*) Ferruginous.
11. Granite soil.
12. Syenite soil.
13. Porphyry soil.
14. Greenstone soil.

Hitchcock states that "Sir Humphrey Davy divides soils into clayey, loamy, chalky, gravelly, sandy, peaty or mossy, boggy and heathy, and moory. "Chaptal," he continues, "makes a more simple division into argillaceous, calcareous, siliceous and sandy. These divisions are very convenient, and it is only for the sake of reference that I have adopted in their stead the geological classifications given above." While his main divisions are based upon the character of the rock, he has recognized the importance of the physical properties by making subdivisions into sandy, argillaceous, red, gray, etc.

Among the more important of the earlier works upon the soils of this country is that of Emmons in New York. In the Natural History Survey of New York, Part V, Agriculture, 1846, he discusses at much length the characteristics and properties of the soils of New York and also gives an agricultural map of that State. This was the first agricultural map published in this country. On pages 229–230 of this report he states: "The common classification of soils is founded on the predominance of certain elements, which we have just described in the foregoing pages. Where, for example, silex predominates, the soil is sandy; and where, on the contrary, clay predominates, it is called argillaceous; a mixture of the two with organic matter is called loam. To be still more specific, loams were designated by the predominance of clay or silex, and thus farmers are wont to speak of a clay loam and sandy loams. In regard to this classification, it is not pretended that it is not useful, and it may be that it is as good as the nature of the case admits. These varieties, however, are met with on almost every farm; and hence, on reflection, it was attempted to class the soils of New York geologically, or according to the products of a section of country, although these sections consist in each case of different formations. The divisions which we have adopted seem to answer well in the territory for which they were framed, but probably may have only a trifling value elsewhere."

Upon this basis the State is divided into six districts, each having certain soils and agricultural characteristics peculiarly its own. Samples of soil were taken from the different divisions and chemical analyses made. These districts were as follows:

1. Highland.
2. Taconic.
3. Hudson and Mohawk.
4. Western or wheat.
5. Southern.
6. Atlanic.

After this work was completed, Emmons went to North Carolina and made similar investigations upon the geology and soils of that State. In 1858 he issued his report upon the Agriculture of the Eastern Counties and followed this by two others in 1860, one of which was a special report upon the Swamp Lands. Emmons recognized the great importance of the physical properties of soils. In the preface to his report upon the Agriculture of the Eastern Counties we find the following:

"In the examination of soils the physical properties require as much attention as the chemical, for in order that a good chemical mixture of elements may be fertile they should possess a certain degree of adhesiveness or closeness which will retain water."

In 1854 D. D. Owen, assisted by Robert Peters, began a study of the chemical composition of the soils of Kentucky in connection with the geological survey of that state. Owen died in 1860, but the work was continued by Peters until his death in 1894. This work may be taken as marking the beginning of the systematic study of the soils of this country by means of chemical analysis. While the authors recognized the great importance of the proper physical condition of the soil, no attempt was made to use the physical properties as a basis of classification. In the later reports Peters separated the soils of the state into thirteen divisions, depending upon their geological origin. A great number of samples, largely virgin soils, were analyzed, but these analyses are not now considered to be of much practical value, because it is distinctly recognized that the fertility of the soil can not be definitely shown by chemical analysis. Peters however believed that the capabilities of the soil could be more cheaply, speedily, and certainly determined by a chemical analysis than by any other means. (See Geol. Survey of Ky., Vol. 2, p. 160, 1885.)

Hilgard's report upon the geology and agriculture of Mississippi was published in 1860, and contained a great deal of information in regard to the soils of that state. The report was accompanied by a geological map, and the close relation between the soils and the geology was pointed out. He also emphasized the great importance of the native vegetation as a means of judging the productivity of the soil. He divided the state into "regions," basing his classification principally upon native vegetation, although he recognized that this followed very closely the origin and physical properties of the soils.

In this connection may be mentioned also the work done under the direction of the same author and published in the Tenth Census as a part of the report upon Cotton Production.[3] This report contains an agricultural map of the cotton states, with detailed descriptions of the soils of the various belts and counties and constitutes one of the most valuable contributions to our knowledge of the soils of these states. Chemical analyses of all the important soils are given, and conclusions as to their fertility were deduced from these analyses. Here as in the work in Mississippi the "designations of the regions are based largely upon the characteristics in regard to tree growth,"

[3] This work has never received the recognition which it merits, probably because of its being contained in a report the name of which gives no idea of the valuable soil information found therein.

but the origin of the soil and its physical properties have been given much consideration. In fact, it may be said that in those parts which are underlain by consolidated material, the character of the rock has been the principal basis, while the timber growth has entered largely into the classification in the Coastal Plains.

The report of the Alabama Geological Survey for 1881–82, by Eugene A. Smith, was devoted to a description of the Agricultural Features of Alabama. Dr. Smith gave in this report quite an able discussion of the general properties of soils, the processes by which they have been formed from the breaking down of the rocks, the influence of the different geological formations upon the character of the soil and upon the agricultural value of the land. The classification used was principally geological, although the author recognized the importance of both the physical and chemical properties of the soil, and treated of these in considerable detail.

One of the first geological surveys to recognize that a geological map and soil map were not necessarily alike was, so far as I have discovered, that of Wisconsin. In 1882, Chamberlain published a soil map of Wisconsin in connection with his report upon the geology of that state. The soils were classified according to their physical characteristics, and this map appears to be the *first soil map published in this country based upon the physical properties of the soil.* It is one of the best general state maps that has ever been issued. The soils are divided as follows:

Sandy.
Sandy loams.
Calcareous sandy loam.
Prairie loams (including several sub-varieties).
Clayey loams, lighter varieties.
Clayey loams, medium and heavy varieties.
Clayey loams, derived from red lacustrine clays.
Humus soils (embracing only those composed mainly of muck and peat).
Black alluvial soils (not shown on map).

In the same report was published a native vegetation map, and the close relation between the soils and vegetation is pointed out.

In the Twelfth Annual Report (1890–91) of the U. S. Geological Survey, Shaler gives an elaborate discussion of the origin and nature of soils. Their classification is considered only so far as it relates to the processes by which they have been formed. The three great divisions, local (sedentary), glacial, and alluvial soils are first discussed. He emphasized the influence of the lack of excess of water upon soil formation. Soils are discussed in more detail under the following heads:

1. Soils derived from underlying rocks.
2. Cliff talus soils.
3. Glacial soils.
4. Volcanic soils.
5. Soils of newly elevated ocean bottom.
6. Alluvial soils.
7. Swamp soils.
8. Marine marshes.
9. Tule lands.
10. Prairie soils.
11. Windblown soils.

In 1891 Whitney made an investigation of the soils of Maryland for the Maryland Experiment Station in cooperation with the United States Department of Agriculture. The results of his studies were published as Bulletin 4 of the Weather Bureau, entitled "The Physical Properties of Soils in their Relation to Crop Production." In this bulletin he pointed out the great importance of the physical properties, especially texture, in determining the amount of moisture that the soil could furnish to the crop, and consequently the suitability of the soil to crops. This fact had been recognized more or less by farmers and soil investigators, but no one heretofore had shown so definitely the correlation between the two.

In 1893 a generalized soil map of Maryland, on which was shown the close relationship between geology and the character of the soil on the one hand, and the character of the soil and the general distribution of crops on the other, was prepared by him for distribution at the Columbian Exposition.

In 1896 Dabney published a general soil map of Tennessee on which the soils are divided into thirteen main divisions. These divisions are based primarily upon the character of the underlying rocks, but the physical characteristics of the soil are also given in the legend. This map was accompanied by a report giving a description of the soils of each division in considerable detail.

The practical importance of Whitney's work in Maryland, previously referred to, was recognized and as a result a Division of Soils was organized in the U. S. Department of Agriculture. Methods for the prosecution of detailed work were perfected, and in 1899 actual field mapping was begun, and since that time many areas have been surveyed by the Bureau of Soils. These represent the first detailed soil maps published in this country.

The classification used by the Bureau of Soils is based upon those differences in the soils, such as origin, texture, structure, color, organic content, etc., which can be recognized by a field examination. It is founded upon the idea that these obvious differences bear a relation to the kind, quantity, and quality of crop which the soil will produce. The classification is therefore very largely physical in character, but all other features which have any apparent influence upon plant growth are considered.

From a study of the soil in various parts of the United States it has been shown that the country can be divided into a number of smaller provinces, each of which contains soils peculiar to itself. This is due to a similarity in the geological processes by which the soil material in these provinces has been formed. Thirteen such provinces have thus far been recognized.

The soil material may differ in character or appearance, although formed by similar processes, due to variation in the source of the material or in the processes of weathering. The soils of a given province are, therefore, further divided into series, which consists of soils very similar in all characteristics except texture. Soils are made up of particles of various sizes and the relative proportion of these different grades determine its texture. There has been established, therefore, different divisions of soils based upon texture, so that the soil series is subdivided into what has been termed different classes. A combination of the series and class characteristics constitute a type which is the unit in soil classification. An example will suffice to illustrate the system:

| | |
|---|---|
| Province | Piedmont Plateau. |
| Series | Cecil. |
| Class | Clay. |
| Type | Cecil clay. |

Marbut and Waters constructed a map of Missouri for the Louisiana Purchase Exposition at St. Louis in 1904. The following shows the different divisions used:

Transported Soils:
- Alluvium.
- Brown loam (loess).
- Black prairie.
- Rolling prairie.
- Level prairie.

Residuary Soils:
- Limestone—shale clay.
- Sandy clay loam.
- Red limestone clay, moderately flinty (Ozark Border).
- Limestone clay, flinty (Ozark Center).
- Red limestone clay.

While geology seems to form the principal basis of the classification, other factors such as texture, color, percentage of stones and topography, are also taken into consideration. The divisions here are however very general, as has been shown by detailed maps of some of the counties. The same types of soil may be found in different divisions, although the percentage of one type may be greater in one division while another type will predominate in another division.

Stevenson published in 1905 a bulletin (Bull. 82, Iowa Experiment Station) upon the principal soil areas of Iowa. The soils in respect to origin are referred to four divisions:

1. *Geest* or soils resulting from the secular decay of rocks.
2. Soils of fluviatile origin, or stream-made soils.
3. Soils of Aeolian origin, or wind-made soils (loess).
4. Soils of glacial origin, or ice-made soils (till).

The author gives a map showing the principal soil areas of Iowa, based largely upon the drift maps of the Iowa Geological Survey. On this map six areas are shown:

Wisconsin drift,
Iowan drift,
Southern Iowa loess,
Missouri loess,
Mississippi loess,
Moraine.

The classification used has for its fundamental conception the idea that the soils of the different glaciations vary, because of the greater amount of leaching and erosion to which the soils of the earlier glaciations have been exposed. There is no doubt that the amount of leaching to which a soil has been subjected has an influence in determining its character, but there are other factors, as topography, for example, which have as much influence upon leaching and erosion as the time during which the material has been subjected to the agencies of weathering.

In addition to the publications which have been referred to in the preceding pages, nearly all of the state geological reports, as well as the folios of the U. S. Geological Survey, have brief descriptions of the soils of the areas covered. It is not possible to mention these separately in this paper or to give all of the more recent soil reports.

In foreign countries a great deal of valuable work has been accomplished, especially in France, Belgium, Germany, the British Isles, Russia, and Japan, and a brief resumé of some of the more important publications are given here.

In France the study of the classification of the soils has been carried on for many years. In a note (Note jointe a la circulaire ministerielle du 2 Septembre 1852, *Annales des Miner,* partie administrative, 5 serie, tome 1, 214) accompanying the first geological map of France by Dufreinoy and Elie de Beaumont, the authors pointed out the close relation between the soils and the underlying rocks and stated that "an agricultural map is in consequence a sort of corollary of the geological chart of the country to which it relates." M. de Caumont had, however, in 1843 constructed an agricultural map of the Department of Calvados and merits to be considered as the originator of agricultural maps. Since his time many other agricultural maps based primarily upon the geology have been published. Among these only a few of the more important can be mentioned. In 1860 M. Jacquot constructed one of the district of Toul which was followed by one of Indre in 1868, of Gers in 1869, and of Sandes in 1873. In the latter he was assisted by M. Rulin. The maps had both a geological and an agricultural legend.

In 1878 M. Delesse prepared similar maps for the Department of Seine and Marne. In 1868 a commission was appointed to construct an agricultural map of the Province of Geneva and the work was completed in 1879. Between 1873 and 1885 a beautiful series of maps of the districts of Ardennes were published. Although made by different authors these maps were upon the same basis and presented uniform legends.

In 1893 a commission was appointed to report upon all matters connected with the making of these agricultural maps, and it is from this report that most of this resumé of the work in France has been taken.[4] This commission recommended that geological maps be used as the basis, but that these should be upon a large scale. Samples of the soils of the different geological formations should be taken and both mechanical and chemical analyses made. The soils are considered as made up of sand, clay, lime, and humus, and the variation of the geological formations in these elements should be shown by the initial of the proper ingredient. For example, if a soil is composed largely of sand with only small amounts of clay, lime and

[4] Rapport Sur les Cartes Agronomiques par M. Adolphe Carnot, Ministere de L'Agriculture, Bulletin, 1893.

humus, the letter S only appears on the map, but if any of the other substances are also present in large amounts then the proper initial is added to show this fact.

In 1894 A. Pagnoul published a report upon "Les Terres Arables du Pas-de-Calais" in which the classification of soils is discussed at considerable length. The author considers three points of view from which the soil may be classified: (1) The texture; (2) the amount of lime; and (3) the amount of humus. A classification based upon one of these factors is easily made, but one in which all three are taken into account becomes much more difficult. According to the amount of humus, soils are divided into: (1) *Ordinary soils* having less than 50 percent of humus; and (2) *Humus soils* having more than 50 percent of humus. Ordinary soils are subdivided into calcareous, clayey and sandy, and a combination of these gives further subdivisions. This system leaves out entirely the origin of the soil and also many important chemical differences. If the sand, clay and humus were always identical in their composition and imparted to the soil certain properties according to the amount present, such a classification would be practicable, but such is not the case. While there are many good points in this system, it is incomplete in that it fails to take into consideration some of the most important differences between soils.

The study of geology in its relation to soil conditions has been carried on in Germany under the direction of Dr. Keilhack, of the Prussian Geological Survey, for more than thirty years, and special *Geologisch-agronomischen* maps of about 43,000 square miles have been made. In the general description of the maps it is stated that "the explanation accompanying each colored map, contains a geological and an agricultural part. In the latter the weathering process and nature of the several soils are described. These are divided into groups according to the chief soil components, and are loamy, sandy, clayey, humus, calcareous, etc." These maps are models of the fineness to which soil mapping may be carried.

In the British Isles the detailed mapping of the superficial deposits is considered as an excellent basis for soil maps, but no true soil maps have been made. The main divisions of the glacial drifts (bowlder-clay, sands, and gravels) have been distinguished. Hall in his book entitled The Soil states that "the basis upon which any soil survey must be constructed is the origin of the soils. The soil surveys simply carry further the work of the Geological Survey as regards the superficial formations. This subdivision of the formations must be based upon the texture. As regards the chemical side, lime is the only constituent that he would consider. His definition of a soil type will show the factors which he would consider in separating soils. "A soil type consists of a body of soil material characterized by a general resemblance in chemical and physical constitution, by a corresponding similarity in the natural flora and by appropriateness to certain crops."

The Japanese have made a study of the characteristics of the soils of their country and have published a number of agricultural maps. These maps are based upon geology which is shown in colors, while the physical characteristics are indicated by means of hatching over the colors. Upon two maps examined the different formations were divided into sand, sandy loam, loam, loamy clay, clay, stony clay, stony loam, and also the occurrence of boulders and lava blocks were shown. By means of symbols the soils are divided also into soils "rich in humus," and those "moderately rich in humus." The Japanese classification is therefore much like that of the French school.

The systematic study of the soils of Russia, which has been carried on so vigorously for the last thirty to forty years, really began when Dokouchayev was commissioned by the old and renowned "Imperial Free Economic Society" to take up the study of the Russian chernozem. The two men who have been most prominent in these investigations are the author just referred to and Kostichev. So ably and energetically has this work been carried on that probably more is known of the nature of the soils of Russia than of any other country of such large geographic extent. Most of the results have been published only in Russian and are therefore not available to the vast majority of students of soils. To Dokouchayev belongs the honor of founding a new school of soil investigations, a school which views the soil as a natural body and having a definite genesis and a distinct nature of its own, and occupying an independent place in the series of formations of the earth's crust. This conception has led to attempts to create a natural classification of soils on a scientific basis. To this branch of soil studies the Russian investigators have made important original contributions.

At the Seventh International Geological Congress in St. Petersburg in 1897 Sibirtzev, the most noted pupil of Dokouchayev, presented a paper summarizing the results of work upon the soils of Russia. As this article gives the views of the Russian school in regard to soil classification it will be well to give a brief summary of it here.

The paper begins with a general discussion of the conditions to be considered in the study of soils. Especial emphasis is laid upon the processes of soil formation, the rocks from which the soil is formed being a secondary consideration. The soil is considered as a biological as well as a geological formation, and unless the material has been influenced by life in some form it must be classed as rock and not soil. The factors which enter into its formation are given, and each existing type of natural soil always corresponds to a definite combination of these soil-forming factors. Climate is considered the most important of these, because the physical, biological, and chemical processes are influenced more or less by and vary with the climate.

The natural classification of soils should be based upon the origin of the soil, not so much the geological origin as the climatic and organic origin. The author points to the marked zones of continental climate and notes that to each zone there is a general type of soil, and that as the climate varies from one zone to the next so vary the soils. From this point of view the soil type is, to a certain extent, the result of the climate. The natural classification of soils must be elaborated, taking the origin as a starting point.

In establishing the chief groups of soils the existing types of their formation in nature must be recognized. A definite or particular combination of soil-forming agents (such as climate, parent rocks, organism, relief of country, etc.) must be formulated. From the study of these factors there can be established a combination of natural conditions which will produce as a result soils having certain characteristics. Upon this foundation the soils of the world are divided into "zones," each of which will exhibit a similarity to the extent to which its content of fine earth and humus reflects the analogous influences of a definite and constant combination of geophysical factors of soil formation. The world is divided into the following soil zones:

1. Latterite soils, or soils of the warm humid tropics and subtropics.
2. Eolian dust soils, formed in continental regions of dry climate.
3. Soils of the dry or desert steppes.
4. Chernozems, formed in connection with herbaceous steppes and prairies of the temperate or cold temperate zones.
5. Soils of the wooded steppes and of the deciduous forests, resembling the chernozems but distinguished by conditions of origin.
6. Peat soils and podzols, properly soils of a cold temperature. They are typically developed under the mixed forests and are ordinarily accompanied by "Ortsteins."
7. Soils of the tundras, formed upon the clay and sandy tundras.

The author points out that among the soil-forming factors there are some which may individualize themselves by diverging from the concordant action of the other factors. Thus, for example, a particular composition of the parent rock may retain its influence on the soil and thus impart special features which are not common to the zonal type. A similar effect may be caused by the local saturation of the soils, due to the configuration of the surface. Soils possessing such characteristics are termed intra-zonal soils, and the author states that there are undoubtedly very many types of intra-zonal soils and gives the following three classes:

1. Alkali soils.
2. Calcareous and humus soils.
3. Marshy soils.

There are in other places soils which can best be considered as incomplete, and these he separates into two divisions: (1) Crude soils, and (2) soil skeletons. He would make also a subdivision of the alluvial soils.

After giving this broad classification, the author notes other classifications which could be made, based upon the physical or chemical properties of the soils. For example, the soils of the different zones can be divided according to their texture into sands, loams, clays, etc., and in this way he connects up this classification with that used by the investigators of Germany, France, and other countries. The author then gives quite an extended discussion of the general characteristics of the soils of the different zones which occur in Russia, and at the end of the volume gives a schematic classification of the soils of Russia.

From this brief resumé of the more important work which has been done in classifying the soils of this and other countries, it can be seen that this line of soil study was developed in foreign countries at an earlier period than in our own. Since the soil survey proper was initiated in the United States, its extension has been very rapid until now there is probably no country in the world where more attention is being given to this kind of work.

# TRANSPIRATION OF WHEAT SEEDLINGS AS AFFECTED BY SOILS, BY SOLUTIONS OF DIFFERENT DENSITIES, AND BY VARIOUS CHEMICAL COMPOUNDS.[1]

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(Contribution from the Department of Soil Technology, Cornell University.)

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## Introduction.

There are vast areas of land throughout the world in which the limiting factor of crop production is the soil moisture; and whatever agent contributes towards its conservation or the prevention of its loss, increases the productive capacity of these areas of fertile soils, and thereby adds to the world's food supply.

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[1] A thesis submitted to the faculty of the Graduate School of Cornell University, in partial fulfillment of the requirement for the degree of Doctor of Philosophy, by George John Bouyoucos, B. S., Ithaca, N. Y., June, 1911. Received for publication Jan. 26, 1912.—Editor.

One of the many factors that causes the most rapid loss of the soil moisture in these arid regions is the transpiration by plants. It is discovered, indeed, that the amount of water usually transpired by the different plants varies from about two to six acre-inches per ton of dry substance. This is certainly an enormous quantity when it is considered that the annual rainfall in some of these countries is only from a trifle to thirty inches.

The factors which influence this loss of water through transpiration are (1) the intensity of light, (2) the water content of the surrounding atmosphere, (3) the temperature of the air and soil, (4) the water content of the soil, (5) the movement of the air, and (6) the concentration and chemical nature of the soil solution. Of all these factors, the last is probably the only one which is more easily under the immediate control of man; yet, strange to say, it has received comparatively little investigation. Indeed, in reviewing the literature, it was surprising to find that the number of experiments planned with this object in view was comparatively few; and some of them have been contradictory and confusing.

Inasmuch as the subject of the influence of the concentration and chemical nature of the soil solution upon the transpiration of plants has this great economic bearing, and considerable theoretical interest as well, it has seemed advisable to investigate the whole subject as thoroughly and systematically as possible. The object of such an investigation should be, it has seemed, to confirm the phenomena observed by other investigators; to discover the truth of some of their contradictory statements; to add, if possible, new knowledge to the subject; and finally to see what practical suggestions could be drawn from the data, which would point towards the solution of the problems of the dry lands.

Accordingly, an investigation was undertaken with the view of ascertaining the effect of various chemical agents and of different densities of solutions, upon the transpiration of plants. The results obtained are presented in the following pages.

## REVIEW OF LITERATURE.[2]

The effect of chemical substances on the transpiration of plants has been known for a long time. Woodward,[3] as early as 1691, noticed that plants grown in pure water transpired more per unit of dry substance produced than plants grown in the rich water of the Thames.

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[2] For the complete citations see the bibliography.

[3] Abbe, Cleveland. Relations between climate and crops (1905); 69.

Senebier[4] appears to be the next to observe that the transpiration of plants was affected by chemical substances and he endeavored to investigate this phenomenon by placing the cut surfaces of branches in solutions containing sulphuric acid, hydrochloric acid, sodium sulphate, potassium nitrate, and potassium tartrate, and noting only the difference in the amount of water taken up but not in that transpired.

The investigation was subsequently resumed by Sachs[5] and later by Burgerstein. Sachs found that when plants were placed in distilled water containing small amounts of $HNO_3$ or KOH, the transpiration was increased in the presence of the acid and decreased in the alkali. He also grew plants in a soil containing $KNO_3$ and $(NH_4)_2SO_4$ and found that the addition of either salt caused a diminution in the transpiration as compared with that in the control soil. Similarly, the application of NaCl or $(NH_4)_2SO_4$ to distilled water also decreased the transpiration.

Burgerstein's[6] investigation consisted of growing plants from one to four days in solutions of $Ca(NO_3)_2$, $KNO_3$, $K_2HPO_4$, $K_2CO_3$, $NH_4NO_3$, $(NH_4)_2SO_4$, $MgSO_4$, NaCl and other chemicals. He found that transpiration increased with the increase in density of all the single salts up to a certain point, above which it began to decrease. A dilute solution of a mixture of salts caused a diminution in transpiration, while a single non-nutrient salt of the same strength caused an increase. The acids accelerated transpiration while the alkalies retarded it.

Schroeder[7] found that the amount of water transpired per unit of dry matter produced increased with the concentration of the nutritive material present, up to a certain density, beyond which it fell.

Sorauer[8] grew plants for eight weeks in a nutrient solution of different concentrations. He found that the relative transpiration decreased with the increase in concentration.

Vesque[9] also studied the effect of chemical substances on transpiration. He observed that when plants have been deprived for some time of a supply of salts and are then placed in a salt solution, they absorb the salt more rapidly than the water; and conversely, when they have been supplied with the salt and are then placed in the water, they absorb the latter more rapidly than they do the former.

[4] Physiologie Vegetale, IV, 1800.

[5] Landw. Vers. Station, Bd. 1: 203, 1859.

[6] Burgerstein, A., Sitzungsber. Akad. Wiss. Math. Nat. cl. 83: 191. 1876.

[7] Ann. Inst. Agr. Moscow. 2 (1896): 188–226.

[8] Allgem. Brauer und Hopfenzeitung 22: 15–19. 1882.

[9] Ann. d. Sci. Nat. Ser. 6, t. IX, 1880.

Heinrich[10] studied the amount of water transpired by oats in a complete nutrient solution of different strengths. He found that transpiration decreased per unit of dry matter with the increase in concentration.

Kiesselbach[11] grew corn for two and a half months in pure river sand watered with a complete nutrient solution. His results show that the amount of water transpired per gram of dry matter tends to increase with the decrease in density.

Lawes[12] investigated the amount of water transpired by wheat, barley, beans, peas, and clover during their growth in sealed pots of soil differently fertilized. To one series he added no fertilizer, to the second series he applied a mineral fertilizer consisting of potassium sulphate, magnesium sulphate, and non-calcium phosphate; to the third series he added the fertilizer used in the second series and in addition, ammonium chloride. In the first two series the plants made a good growth, but in the last they were very unhealthy. As a result of this investigation he found that in the case of wheat, peas and clover, the application of the mineral fertilizer decreased the amount of water required to produce a unit of dry substance, while the mineral plus the ammoniacal fertilizer diminished it still more. In the case of beans, however, the addition of the mineral fertilizer caused an increase in transpiration, and in the case of the barley, the application of the ammoniacal fertilizer brought about a similar increase.

Maercker[13] grew white mustard in an artificial soil composed of sand and 2.5 percent of peat, contained in zinc pots. He added to the soil different amounts of moisture and various quantities of kainit and carnallite, and studied the effect of these salts upon the amount of water required to produce a given quantity of dry substance. He failed to seal the pots to prevent the direct evaporation from the surface of the soil, but the results he obtained go to indicate that the application of the potash salts produced a distinct economy in the absorption of water, this being more marked in the lower than in the higher moisture content.

Pagnoul[14] reports an experiment in which he grew fescue grass from March 30 to June 21 in a poor clay soil to which no treatment was applied, and in a rich calcareous soil to which dried blood and nitrate of potash were added; the moisture content being the same in both cases. The plants were harvested at two different periods. The results show that in the first period the plants in the poor soil transpired 1,190 grams of water per gram of dry weight as compared with a transpiration of 555 grams in the rich soil. In the second period the differences were 1,053 and 581 grams of water respectively.

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[10] Zweiter. Ber. landw. Vers. Sta. Rostock. (1894): 170–174.

[11] Nebraska Agr. Expt. Sta., 23d Ann. Rept. (1910): 138.

[12] Rothamsted Memoirs 1: 1–28. 1886.

[13] Arbeit Landw. Gesells. Heft 20. 1896.

[14] Sta. Agron. du Pas de Calais (1898): 10–15.

Davy,[15] Hellriegel,[15] and Deherain[15] have reported that the amount of water required to produce a unit quantity of dry matter was greater on poor soils than on good fertile ones.

Preul[16] has also found that wheat plants growing in good soils required less water per gram of dry plant substance than do those grown in poor soils.

These observations were further confirmed by the recent researches of Dr. Widtsoe.[17] In an extended series of experiments to study the evaporation and transpiration in the arid regions he found that fallowing or cultivation tended to decrease the units of water per unit of dry substance produced. Likewise, fertile soils produced crops with a smaller amount of water than the unfertile ones, and the addition of fertilizers to the latter enabled them to produce dry matter at a lower water cost.

King[18] has shown that strong vigorous growth and high yield of dry matter are always associated with a low relative transpiration. He has also noticed that the amount of water used by plants on summer-fallowed land is smaller than on continuously cropped lands.

Warington,[19] after comparing the results of Lawes and Gilbert, Hellriegel, King, and Wollny, concludes that the factors which influence the relation of water supply and produce are the amount of water supplied, and its richness or poverty in plant food.

In the course of investigations on the increase in plant growth by fertilizers in soil pots, Gardner[20] noticed that as the fertilizers increased plant growth, the amount of water transpired per unit of growth was usually diminished.

Von Seelhorst[21] has shown that the amount of water required by oats to produce a unit of dry matter decreased as the yield of dry matter increased, and that the relation between growth and transpiration is influenced by fertilizers and by the nature of the soil.

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[15] Die Transpiration der Pflanzen (1904): 145.

[16] J. F. Landw. 56: *228–271*. 1908.

[17] Bul. 105, Utah Agr. Coll. Exp. Sta. 1909.

[18] Physics of Agr., Madison, Wis. (1907): 137.

[19] Physical Properties of Soil (1900): 53.

[20] Bul. 48, Bureau of Soils, U. S. Dept. of Agr. (1908): 54–56.

[21] Jour. f. Landw. 47: 369–378. 1899.

He[22] has also found that a loam soil gave a greater economy in the use of water than a sandy soil.

In a series of pot experiments by the Hawaii[23] Agricultural Experiment Station to determine the influence of chemical fertilizers and natural manures upon the growth and composition of the rice plant, the amount of water transpired was taken as a criterion of growth. It was noticed that $NaNO_3$, $K_2SO_4$ and $CaH_4(PO_4)_2$, which gave the most consistent results, produced the largest amount of plant growth and at the same time gave the smallest proportionate transpiration.

Harter[24] conducted an experiment to ascertain whether the presence of a mixture of salts, principally NaCl, will affect the structure of the plants and incidently the transpiration. He found that when the salts were present in sufficient amounts to cause any structural modifications of the plants, the transpiration was considerably reduced, but when they were present in very small quantities, it was decidedly increased.

In a series of experiments to ascertain whether or not sodium caused an increase in the green weight of wheat seedlings when the supply of the potassium present was deficient, Hartwell[25] et al. took record of the transpiration of the plants during their growth. Their results show that the increase in green weight, due to an abundance of potassium as compared with the deficiency, was almost always greater than the increase in transpiration; and that the increase caused by the addition of sodium to the deficient amount of potassium, was likewise greater in green weight than in transpiration.

The same investigators[25] report still another series of experiments conducted to secure indications as to whether varieties of plants which were most benefited by liming, were likewise most susceptible to injury by certain acids when their seedlings were grown in nutrient solution possessing definite degrees of acidity. Transpiration was recorded as a partial indication of growth. The results show that acids depressed transpiration a great deal more than equal strengths of alkalies, as compared with distilled water.

Reed[26] has recently attempted to study the specific effect of different chemical agents upon the units of water transpired per unit of green weight produced in wheat seedlings grown from 18 to 21 days in soil, soil extract, and solution cultures, treated with the following chemical substances: $NaNO_3$, $Na_2HPO_4$, $K_2SO_4$, KCl, $CaCO_3$, $CaH_4(PO_4)_2$, HCl, $HNO_3$, $H_2SO_4$, NaOH, KOH, pyrogallol and tannic acid. The inorganic salts were added both to the soil and soil extract, and the acids, alkalies, and organic substances only to the soil extract. He also treated distilled water with carbon black, ferric hydrate, and quartz flour.

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[22] Jour. f. Landw. 54: 313–342. 1906.

[23] Ann. Rept. Hawaii Agr. Expt. Sta. (1907): 79.

[24] Bul. 134, Bureau of Plant Industry, U. S. Dept. of Agr. (1908): 719.

[25] Ann. Rept. R. I. Expt. Sta. 20: 299–380. 1908.

[26] Bot. Gaz. 49: 81–110. 1910.

The results show that the respective chemical agents employed had a definite influence on the correlative transpiration. The lime and sodium phosphate increased the transpiration, but the potassium salts decreased it, while sodium nitrate gave indefinite results. Inorganic acids retarded transpiration, while organic acids were somewhat variable. Pyrogallol and tannic acid both accelerated transpiration.

Sampson and Allen[27] studied the effect of acids, alkalies and soil types on transpiration. They found that as a general rule acid solutions accelerated and alkaline solutions retarded transpiration. There appeared also to be a slight tendency for the transpiration to be depressed in the better soils.

Livingstone[28] conducted a series of experiments to ascertain the relation between the growth and transpiration of wheat. As a result of his investigation he has come to the conclusion that the total transpiration is proportional to the leaf surface and approximately proportional to the green and dry weight of the tops.

## General Methods of Investigation.

In the present work the effect of the different densities of solutions and of the various chemical agents, upon the transpiration of plants, was usually studied in water, sand, and soil cultures, at the same time and under the same conditions.

The water cultures were prepared and conducted according to the methods recommended by the Bureau of Soils,[29] with few modifications.

The method consisted of cutting four triangular-shaped slits around the circumference of corks which fitted the mouths of black painted glass bottles of a capacity of 120 c.c. The inner angle of each cork wedge thus made was then truncated by the removal of enough cork to allow the fitting of seedlings between the inner truncated angle of the wedge and that of the slit in the cork. Four equally sized and vigorous wheat seedlings were then fitted into the slits of each stopper with their seeds just below the latter, and a rubber band was placed around the cork to hold the wedges in place. The wedges exerted enough pressure on the seedlings to hold them in their respective positions, but not too great to interfere with their growth in any way. The stopper containing the plants was then pressed firmly into the neck of the bottle which was filled with solution just below the seeds of the plants. The seedlings employed were first germinated in moist sand contained in pans, and allowed to reach the height of about one inch before they were removed from the sand and transferred into the solution.

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[27] Minn. Bot. Studies 4 (1909): 33–59.

[28] Bot. Gaz. 40: 178–195. 1905.

[29] Bul. 23, Bureau of Soils, U. S. Dept. of Agr. 1904.

In pulling out the seedlings from the quartz there was some danger of damaging their tender and delicate roots if the quartz was too dry, but if it was very wet there was no such danger.

The solution cultures prepared as described above allowed practically no direct evaporation from the solution but only through the exposed surfaces of the plants. Occasionally, when the cork stoppers became moistened by the layer of concentrated solution held around the wall of the mouth of the bottle by surface tension, a rapid evaporation would take place through the corks by capillarity. The loss of water in this manner was easily prevented by dipping the stoppers, into melted paraffine, after the slits were cut around them, and the holes under the wedges were then opened by a thin wire, just large enough to fit the seedlings. The thin layer of paraffine formed around the stopper not only closed the pores of the latter but also prevented the direct communication between the stopper and the solution when they were in direct contact with each other.

The cultures were weighed at intervals of three to four days and the loss in weight was taken as a measure of transpiration. The decrease was replaced at each time with the solution, and about once every week the entire solution was changed. In this manner the entire root system was constantly kept covered with the solution, and stagnation or any inequality in concentration in the latter was avoided by its frequent renewal.

The tests for the soil or sand cultures were conducted in the paraffined wire baskets, also recommended by the Bureau of Soils.[30]

The baskets used for this work were about three inches deep and three inches wide. Those in which soil was added were prepared by dipping the rim about one inch in height in melted paraffine, with the intermediate cooling in water until a firm wall was formed. Then exactly the same amount of soil was added to each basket, and pressed firmly at the bottom and at the sides so it formed a very close contact with the walls. The baskets were next dipped several times in melted paraffine slightly above the lower edge of the paraffined rim, until a thick coating was formed which cemented the outer surface of the mass of soil to the walls of the pots. The soil was next brought up to the desired moisture content by the addition of a certain amount of the solution and then an equal number of well selected seeds were planted in each pot, and the weight of the latter recorded. When the seeds were germinated and the seedlings were about one inch in height, each basket was reweighed and the loss in weight was replenished by the addition of water. Then an equal number of the healthiest and most vigorous seedlings of as near as possible the same size, were selected and the remainder pulled out. The baskets were next sealed and their final weight recorded.

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[30] Loc. cit.

The sealing of the baskets was done somewhat differently from that recommended by the Bureau of Soils. The new method was devised in the course of the investigation and consisted of placing over the selected seedlings small glass tubes with a diameter sufficiently large to permit the fitting of the seedlings through them, and then melted paraffine was poured over the surface of the soil. The glass tubes being pushed a little below the surface of the soil prevented the hot paraffine from coming in contact with the seedlings and thus injuring them.

This method has given very satisfactory results and is probably the better of the two, for the following reasons: (1) It takes less time to seal a basket; (2) it further reduces the evaporation from the surface of the soil because it forms a more uniform cover; gives less amount of exposed surface of the soil through the holes; creates a much closer contact between the surface of the soil and the cover; and (3) it reduces the possibility of injury to the plants during manipulation.

The only serious objection to this method is that if the paraffine is too warm it may heat the glass tubes, and if the seedlings are in close contact with them, they may be scalded. This danger can be easily avoided, however, by placing over the glass tubes very thin rubber tubing before they are placed over the plants; and also by not using too warm paraffine.

Just as in the case of the water cultures, the baskets were weighed at intervals of three to four days and the loss in weight was attributed to transpiration. The loss was replenished in this case not by the solution as in the case of the water cultures, but by distilled water only.

The sand cultures were prepared and conducted exactly like the above, excepting that the sand was added in the baskets after they were entirely paraffined.

The different experiments were usually continued from three to four weeks. During this time the growth and progress of the plants were carefully noted. At the termination of each experiment both the tops and the roots were carefully examined as to their general appearance and characteristics. The tops were harvested directly above the seed, washed thoroughly with distilled water to remove any sand particles that might adhere on them, and their dry weight determined on a delicate chemical balance, to the fourth decimal place. Similarly, the roots were thoroughly washed and their dry weight determined, but in this case it was found practically impossible to remove all the fine particles of sand adhering to the root hairs, and since the results could not be very reliable, this line of study was discontinued.

The sand and soil used throughout the investigation were numbers 1, 2, and 3½, and Dunkirk clay and Dunkirk sandy loam respectively. The numbers of the sand represent the size in millimeters in diameter.

The seed employed throughout the work was Pringle's Champion and Little Club. In order to eliminate errors which are due to inherent differences in the individuality of the plants, a large number of seedlings of the same variety was used for the different kinds of cultures within the same experiment. For the solution cultures there were usually from three to six bottles with four plants in each bottle, and for the sand and soil cultures from three to six baskets with five to seven plants in each, for each density of solution. Special care was exercised to select seedlings of uniform size and as nearly of the same vigor and health, as possible.

## EXPERIMENTAL RESULTS.

### *Transpiration of Wheat Seedlings as Affected by Different Densities of a Complete Nutrient Solution, in Water, Sand and Soil Cultures.*

The object of this line of the investigation was to determine the effect of different densities of a complete nutrient solution on the amount of water transpired by wheat seedlings to produce a unit of dry matter. For this purpose the wheat plants were grown in solution, sand and soil cultures, containing various densities of a full nutrient solution. The concentrations of this solution were seven in number, and ranged in strength from 0.0 to 4,500 parts per million. The sand and soil cultures were used first to duplicate the water cultures, and secondly, to see whether the different densities of the solution would affect the transpiration in these cultures, in the same order or in the same magnitude as in the water cultures. For the determination of these two points, all the three different kinds of cultures were conducted at the same time and under the same conditions, in order that their results might be comparable. The sand and soil employed were of various sized particles. The sand consisted of three different sizes, namely, numbers 1, 2 and 3½. In other words, those which could pass through a mesh of 1, 2, and 3½ millimeters, respectively, in diameter. The soil consisted of a Dunkirk clay loam and of a Dunkirk sandy loam, the first being assumed to be the finer of the two. The object of employing the sand and soil of different textures, was to ascertain whether the size of particles exerted any influence upon the density of the solution in affecting the transpiration. To investigate this point, the cultures of the various sizes of sand, and of the two soils, were carried on at the same time and under the same conditions.

In order to obtain definite and conclusive evidence on this part of the investigation, the three different kinds of cultures were repeated a large number of times. The solution and sand cultures were repeated five times each, and the soil cultures two times. Inasmuch, however, as there were two different sizes of sand in four out of five cases, and two different kinds of soil in both instances, and since all received the same treatment, there were really nine sand and four soil cultures, respectively. The solution cultures conducted at the different times contained, in each density, from three to five bottles with four plants in each receptacle. The sand and soil cultures, also carried on at different periods, contained, in each density, from three to six baskets with five to six plants in each. The total number of plants in each concentration in the different cultures was, therefore, 96 in the five solution cultures, 204 in the nine sand cultures and 80 in the four soil cultures.

Each basket within the same density, and each group of baskets representing the various concentrations, both in the sand and soil cultures, contained, at each time, exactly the same amount of sand or soil, and exactly the same percentage of moisture content. The moisture content was brought up to the desired point by the addition of the nutrient solution, and then kept at that point throughout the duration of the experiments, by the addition of distilled water.

All the experiments conducted at the different periods always received the same density of the same complete nutrient solution. The composition and preparation of the latter are shown below.

| | Grams. |
|---|---|
| Calcium Nitrate | 27.0 |
| Magnesium Sulphate | 6.0 |
| Potassium Phosphate (Monobasic) | 15.0 |
| Ferric Sulphate | 0.5 |
| Potassium Chloride | 7.5 |
| Total | 56.0 |

These salts were dissolved in 10 liters of distilled water. In order to avoid precipitation as completely as possible, they were dissolved in the following manner and then mixed together:

$Ca(NO_3)_2$ plus KCl dissolved in 3 liters of water.

$MgSO_4$ plus $Fe_2(SO_4)_3$ dissolved in 3 liters of water.

$K_2HPO_4$ dissolved in 3 liters of water.

They were then brought together and the volume made up to 10 liters.

Even when the above precautions were taken, some precipitation did take place and the solution had to be filtered through the regular filter paper. The density of the filtrate was then determined by evaporating 50 c.c. of the solution and weighing the residue. This gave 4,500 parts per million. From this stock solution, the different densities needed for the experiments were prepared. These various concentrations with their strength in p.p.m., and in electrical resistance as determined by the Wheatstone bridge, are shown herewith.

| Density in p.p.m. | Density in Ohms. |
|---|---|
| 4,500.0 | 66.0 |
| 2,250.0 | 121.1 |
| 750.0 | 327.4 |
| 375.0 | 588.3 |
| 187.5 | 1,115.5 |
| 93.5 | 2,775.0 |
| 0.0 | 10,000.0 |

Each experiment was continued three weeks. During this period, the daily development and general appearance of the plants were carefully noted. It was observed that, as a general rule, the seedlings grown in the higher densities always made, at the beginning, a much slower growth than those in the lower concentrations. Indeed, it always appeared that the rate of growth increased as the density decreased. After the first four or five days, however, this order was reversed; the plants in the higher densities began to grow very rapidly and the rate or magnitude of growth became quite uniformly proportional to the concentration.

In connection with the above observation, it might also be mentioned that the germination of the seeds was also retarded by the higher densities. The time required to sprout was proportional to the concentration, and the difference in time, between the two extremes, was from one to two days.

At the termination of each experiment a careful examination was always made of the total growth and of the general appearance of the plants, including both the tops and the roots, in all three kinds of cultures. In the case of the tops, it was observed that they were healthy and vigorous, and their total growth always tended to increase with the increase in density. The roots also always appeared to be healthy, vigorous and turgid, and their total weight to be proportional to the actual weight of the tops. As to the latter relation, several attempts were made to confirm it quantitatively by determining the dry weight of the roots and then comparing this with the dry weight of the tops. It was found, however, that this comparison was not reliable, because the roots in the different densities contained various amounts of fine sand particles which were practically impossible to wash out. In view of this difficulty, the determination of the dry weight of the roots had to be abandoned and, therefore, the relation of the roots to tops, roots to transpiration, and roots to density, all of which would have been of great interest, could not be ascertained.

The dry matter of the tops was determined by drying them in the water oven at boiling water for about 10 hours, and then after cooling, they were weighed on a chemical balance to the fourth decimal place. The total dry matter was then compared with the total transpiration, and the amount of water required to produce one gram of dry substance, was calculated.

TABLE I.—*Effect of Different Densities of a Complete Nutrient Solution Upon the Transpiration Per Gram of Dry Matter of Wheat Seedlings Grown in Solution Cultures. Averages of Five Series.*

| Density of Solution in p.p.m. | Grams of Dry Matter Produced. | Grams of Water Transpired. | Grams of Transpiration per Gram of Dry Matter. |
|---|---|---|---|
| 4,500 | .7071 | 298.67 | 360.0 |
| 2,250 | .6017 | 290.99 | 415.0 |
| 750 | .5530 | 272.98 | 426.7 |
| 375 | .4995 | 266.52 | 454.8 |
| 187.5 | .4494 | 243.25 | 471.4 |
| 93.5 | .3808 | 196.13 | 463.7 |
| 0.0 | .2766 | 83.63 | 256.8 |

Mention has already been made that this line of the research involved five series of solution cultures, nine series of sand cultures, and four series of soil cultures. Inasmuch as all the different series within the same culture received practically the same treatment, and show almost the same order of results, we are warranted in arranging their individual results, in averages. The main conclusions will, therefore, be drawn from these averages. These data are given in Tables I, II and III. Each table is accompanied by a figure to illustrate its salient facts in a graphical form.

TABLE II.—*Effect of Different Densities of a Complete Nutrient Solution Upon the Transpiration Per Gram of Dry Matter of Wheat Seedlings Grown in Sand Cultures. Averages of Nine Series.*

| Density of Solution in p.p.m. | Grams of Dry Matter Produced. | Grams of Water Transpired. | Grams of Transpiration per Gram of Dry Matter. |
|---|---|---|---|
| 4,500 | .9071 | 373.64 | 374.6 |
| 2,250 | .7965 | 370.21 | 425.7 |
| 750 | .6179 | 275.71 | 446.7 |
| 375 | .4862 | 232.95 | 463.7 |
| 187.5 | .4307 | 193.56 | 460.6 |
| 93.5 | .3951 | 173.71 | 442.6 |
| 0.0 | .3601 | 151.19 | 429.4 |

TABLE III.—*Effect of Different Densities of a Complete Nutrient Solution Upon the Transpiration Per Gram of Dry Matter of Wheat Seedlings Grown in Soil Cultures. Averages of Four Series.*

| Density of Solution in p.p.m. | Grams of Dry Matter Produced. | Grams of Water Transpired. | Grams of Transpiration per Gram of Dry Matter. |
|---|---|---|---|
| 4,500 | .8077 | 407.8 | 501.1 |
| 2,250 | .6127 | 359.3 | 584.2 |
| 750 | .4444 | 251.5 | 570.4 |
| 375 | .3838 | 232.9 | 584.0 |
| 187.5 | .3718 | 235.7 | 618.0 |
| 93.5 | .3709 | 239.1 | 645.4 |
| 0.0 | .3392 | 204.1 | 588.9 |

It is evident from the tables and Figs. 6–8 that the different densities of the complete nutrient solution have a very significant effect upon the transpiration of the wheat seedlings, and that this effect manifests itself in all three of the different cultures. It will be seen that the transpiration per gram of dry matter increases in every one of the three cultures with the decrease in density, until a certain dilution is reached and then decreases with a further decrease in concentration. To state the same thing in the converse form, the relative transpiration rises with the concentration up to a certain point beyond which it declines with a further increase in density. The concentration at which the change occurs is different for the various cultures, but it lies between 93.5 to 375 parts per million. For the solution cultures (Table I, Fig. 6), it is at 187.5 p.p.m.; for the sand culture (Table II, Fig. 7), it is 375 p.p.m.; and for the soil culture (Table III, Fig. 8), it is at 93.5 p.p.m. The regularity with which the correlative transpiration at first increases with the diminution in density and then declines with the further reduction in concentration, is very uniform for the sand and solution cultures, but in the soil culture there is one exception. It will be observed that in both the water and sand cultures, there is not the slightest break in the curve from the highest density to that where the change takes place, nor from there to the lowest concentration. In the soil culture (Fig. 8), however, there is one irregularity in the curve before the

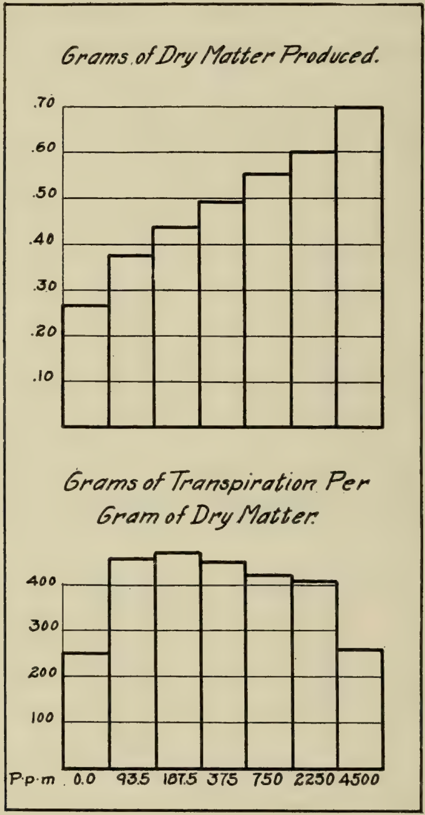

FIG. 6.—Effect of different densities of a complete nutrient solution upon the transpiration per gram of dry matter of wheat seedlings grown in solution cultures. Averages of five series.

density where the change commences, is reached. Undoubtedly, however, this discrepancy would probably not be noticed had there been as many trials of this culture as there were in the other two.

So far, therefore, as these results may be considered conclusive, they go to show two facts; first, that the relative transpiration increases with the decrease in density, down to a certain point; and secondly, after this point, it declines with the further diminution in

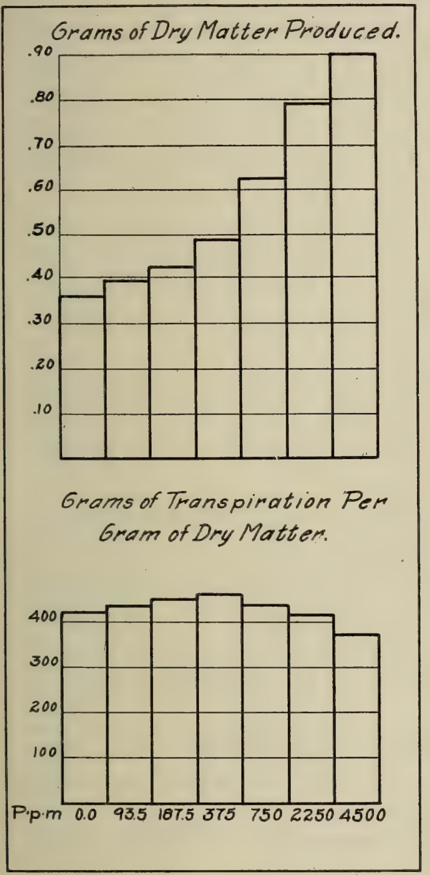

FIG. 7.

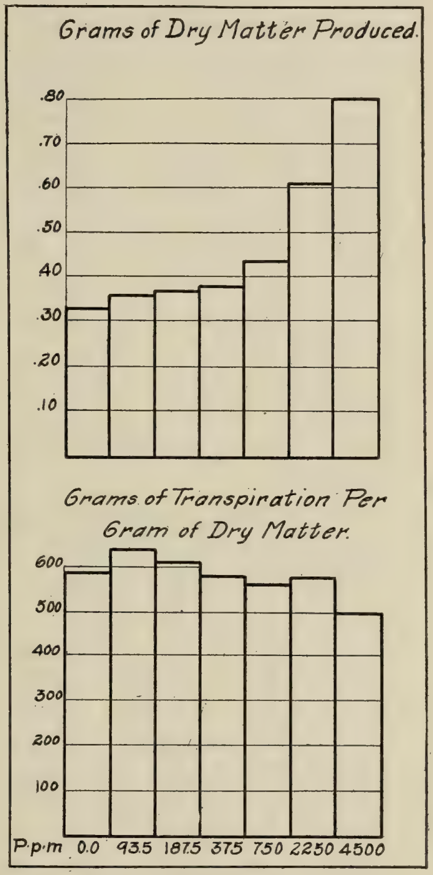

FIG. 8.

FIG. 7.—Effect of different densities of a complete nutrient solution upon the transpiration per gram of dry matter of wheat seedlings grown in sand cultures. Averages of nine series.

FIG. 8.—Effect of different densities of a complete nutrient solution upon the transpiration per gram of dry matter of wheat seedlings grown in soil cultures. Averages of four series.

concentration. Evidently, the highest and lowest densities diminish it the most, and the intermediate ones the least.

These results are significant not only on account of the relation they indicate between the density and the transpiration, but also because they throw some doubt upon the statement made by certain investigators[31] that the total transpiration is as good a criterion for measuring plant growth as the weight of the plants. Indeed, the foregoing data tend to disprove this view most decidedly. They show that the media or density of solution in which the plants are grown, have a most significant effect upon the correlative transpiration, and that the latter varies, in some cases, between the different densities within the same culture, from 360.0 to 471.4 grams, or a difference of 111.4 grams. In view of these facts, therefore, it can hardly be considered, from these results at least, that the total transpiration is an accurate and true criterion of measure of plant growth even though the total transpiration may be to a certain extent a function of plant growth.

The next question to decide is, what forces cause these phenomena. It must be stated in advance that no definite and proved explanation can be offered, though the following suggestions may be worth considering.

The increase in the relative transpiration with the decrease in density down to the point where the change takes place, may be attributed to three factors; namely, (1) to the different modification of the structure of the plants, brought about by the different densities; (2) to the different osmotic pressure of the various concentrations; and (3) to the different densities of the cell sap of the plants grown in the various densities of solution.

As to the first factor, it was realized at the beginning of the investigation that if very high densities were used, they would prove not only harmful to the plants but they would also modify their structure or anatomy, i. e., cause them to assume the xerophytic form, which would tend to reduce transpiration, and thus destroy the central object of the research. The concentrations employed, therefore, were of a strength below that which would bring about the above conditions. Furthermore, from a large number of examinations, there was never observed any noticeable differences in the external structure of the plants grown in the different solutions. Under these conditions, therefore, it seems that the increase of the relative transpiration with the diminution in density, is not due to any difference in the outer anatomy of the plants grown in the various concentrations.

[31] Bot. Gaz. 40: 178–195. 1905.

In order that the second factor may be true, it is conceived that in the highest concentrated solution, there is present a high osmotic pressure, but not so high as to cause plasmolysis. This osmotic pressure is probably caused by the attraction that the molecules and ions in the solution have for water. When the plants are placed in this medium, the density of their cell sap becomes more or less adjusted with that of this outside solution. In this condition, the osmotic pressure of both the cell sap and the solution are relatively equal, and one has as much attraction for water as the other. Since, however, the plant juice tends to lose some of its water through transpiration, its density becomes greater, and consequently, the equilibrium is disturbed. In order to restore this equilibrium and to keep it constant, the cell sap exerts a demand for water upon the outside solution. The latter, however, can give up only a limited amount of its water because if it yields too much it, itself, becomes more concentrated and it will have the opposite pull. In this manner, the surrounding solution acts as a regulator of the amount of water the plants can absorb; it allows them to consume a sufficient quantity for their maximum growth but not any surplus. Again, as the cell sap becomes concentrated by the loss of water, its osmotic pressure, vapor tension and viscosity also become more intensified, and since they all tend to withhold water, they also help to reduce the transpiration.

Now as the density of the solution decreases, its osmotic pressure diminishes practically proportionally, for the absolute number of molecules and ions becomes less. In this case, the actual number of free or available molecules of water becomes greater. That is to say, as the actual number of molecules and ions of the salts decreases, the absolute number of free or available molecules of water rises in direct ratio. In this condition, the regulative capacity or the water attraction pressure of the outside solution is reduced, and the plants can now take up water with greater ease, or as rapidly as they can give it off.

It seems then, that in the highest density of solution, the absolute number of molecules and ions is very large, and of necessity the osmotic pressure is high. The great number of molecules and ions present leave very few or no free molecules of water in the solution. All these conditions tend to retain the water, and consequently, serve as regulators of the amount of moisture the plants can imbibe, i. e., they permit them to absorb a diminished quantity from what the external conditions demand upon them to transpire. As the density of the solution decreases, however, the actual number of molecules and ions diminishes, and hence the osmotic pressure also; while the actual number of free or available molecules of water increases proportionally, and consequently, the transpiration is increased in the same ratio, because the plants can now absorb water with greater facility and thus satisfy the demands of the external conditions. The ultimate result of all these is what has already been obtained, namely, the transpiration per gram of dry matter increases with the decline in concentration down to a certain point.

In order that the third factor may be correct, it is assumed that the density of the cell sap of the plants increases with the concentration of the solution in which they are grown. That is to say, the density of the cell sap of the plants grown in the most highly concentrated solution is greater than that of the plants grown in the less dense solution, and that it decreases with the diminution in density of the solution. In this condition, the high concentration of the cell sap in the solution of high density, would possess very high osmotic pressure, viscosity and low vapor tension, all of which tend to produce the same effect, namely, to retain water. As the density of the cell sap decreases, however, the degree of magnitude in which these physical properties diminish transpiration, decreases proportionally and consequently, the evaporation of the water from the surface of the plants increases and, therefore, results in what has already been mentioned.

It will have already been seen that both factors may and can act together at the same time, for both tend to produce the same effect. This is easy to conceive. As the density of the solution decreases, its osmotic pressure diminishes almost proportionally and, therefore, everything else being equal, the ease or facility with which the plants can absorb water increases in the same ratio. Also as the density of the cell sap decreases, the degree or power of its physical properties to diminish evaporation decreases, and therefore, the rapidity with which the water tends to go off rises proportionally. Thus, in either case, the amount of water lost increases directly with the reduction in concentration, and since the density of the cell sap diminishes with the increase in dilution of the outside solution, the increased transpiration per unit of growth as already noted, is probably the result of the reduced intensity of the physical properties of both factors.

The arguments brought forward in regard to the second factor, are reasoned mainly from what is already known about the law of osmotic pressure in different densities of solution containing electrolytes. It was inferred that since the osmotic pressure decreases with the diminution in density, the increased relative transpiration with the increase in dilution down to the certain point, might be due to this. As to whether this inference or assumption is correct, cannot be asserted with absolute positiveness. Theoretically, it is true.

The assumption made concerning the third factor, namely, that the density of the cell sap increases with the concentration of the outside solution, was tested experimentally, and from all evidence it appears to be correct. This point was investigated by extracting the cell sap of the plants grown in the different concentrations of solution and determining its density. The extraction of the plant juice was performed by placing the green plants in a mortar, crushing them with a pestle till the sap was pressed out, and washing out the latter with distilled water. The pestling and washing were continued till the plant juice had been taken out, and only the white fiber was left behind. The latter was then put in a piece of cheesecloth and rinsed several times in order to wash out every trace of the cell sap, and then pressed very firmly inside of the cloth to strain out all the solution. The extract was then filtered through a regular filter paper, its volume brought up to a definite point, and its density determined. For the latter, two methods were used: (1) The freezing point; and (2) the electrical resistance, as determined by the Wheatstone bridge. A good deal of preliminary work was done with both methods, and it was found that both gave exactly the same results, namely, that the density of the cell sap decreased with the diminution in concentration of the outside solution. Since the resistance method was the quicker and the simpler of the two, the majority of the final determinations were made with this method. While the resistance may not be as accurate or give as definite quantitative results as the freezing point, it shows, however, the comparative relation sought.

The plants used in this work were wheat. Beans were also used, but only in one case. Both kinds of plants were grown in solution cultures from about three to six weeks.

In order that the density of the cell sap may be comparable among the different densities of solution, exactly the same weight of green plants grown in the various concentrations, was taken.

*Experiment I.*—This experiment consisted of growing wheat seedlings for 16 days in two different densities of solution, namely, 4,500 and 93.5 p.p.m. At the end of the above period they were harvested and exactly 3.9610 grams of green weight was taken, the cell sap was extracted by the method already described, diluted to 200 c.c. with distilled water, and the density determined by both methods. The data obtained are given in the following tables.

TABLE IV.—*Density of Cell Sap as Determined by the Freezing Point Method.*

| P.p.m. of Solution in which Plants Grew. | Freezing Point of the Cell Sap. |
|---|---|
| 0.0 | 4.200° C. |
| 93.5 | 4.190° C. |
| 4,500.0 | 4.175° C. |

TABLE V.—*Density of Cell Sap as Determined by the Electrical Resistance Method.*

| P.p.m. of Solution in which Plants Grew. | Resistance of Cell Sap in Ohms. |
|---|---|
| 93.5 | 592.5 |
| 4,500.0 | 411.9 |

It is evident from both tables that the density of the cell sap diminished with the decrease in density of the solution. It will be seen that in the first table the cell sap of the plants grown in the highest density of solution lowered the freezing point .015° C. more than that in the lower concentration, and .025° C. more than in the check. In the second table, the electrical resistance was 180.6 ohms less in the plant juice derived from the plants grown in the highest concentrated solution than in the other.

*Experiment II.*—This experiment was the same as the preceding one except that in this case only the electrical resistance method was used to measure the density of the cell sap. The results obtained are given in the following table.

TABLE VI.—*Density of Cell Sap as Determined by the Electrical Resistance Method.*

| P.p.m. of Solution in which Plants Grew. | Resistance of Cell Sap in Ohms. |
|---|---|
| 93.5 | 422.0 |
| 4,500.0 | 210.9 |

It will be observed that, as in the foregoing experiment, the density of the cell sap was decreased with the reduction in concentration of the solution.

These experiments were repeated also in sand cultures and the data obtained were identical with those from the water cultures.

*Experiment III.*—In this experiment beans were used instead of wheat the object being to see whether the above relation would hold true with other species. These plants were allowed to grow for 45 days in a complete nutrient solution of 4,500 and 750 p.p.m. Exactly 5.6900 grams of green weight were taken, the cell sap extracted as usual, diluted to 500 c.c., and the density determined by the electrical resistance method. The table below contains the results secured in this case.

TABLE VII.—*Density of Cell Sap of Bean Seedlings as Determined by the Electrical Resistance Method.*

| P.p.m. of Solution in which Plants Grew. | Resistance of Cell Sap in Ohms. |
|---|---|
| 750 | 1,479.6 |
| 4,500 | 1,158.1 |

These figures show that the foregoing relation holds true also with beans. It will be noticed that the 4,500 p.p.m. solution gave 321.5 ohms more concentrated cell sap than the 750 p.p.m. solution.

*Experiment IV.*—This experiment consisted of growing wheat seedlings for 15 days in solutions of $N/50$ and $N/250$ of $CaCl_2$ to each one of which was added exactly the same amount of a complete nutrient solution in order that the plants might make a normal growth. The object of this series was to see whether the density of the cell sap among the different densities of the non-nutrient solution, would run in the same order as that of the different concentrations of the complete nutrient solution already noted. The cell sap was extracted, in this case, from 1.6330 grams of green weight diluted to 200 c.c., and the density determined by the electrical resistance method. Following are the results obtained:

TABLE VIII.—*Density of Cell Sap of Wheat Seedlings as Determined by the Electrical Resistance Method.*

| P.p.m. of Solution in which Plants Grew. | Resistance of Cell Sap in Ohms. |
|---|---|
| $CaCl_3$ $N/250$ | 1,007.2 |
| $CaCl_2$ $N/50$ | 952.8 |

It is evident that even with the non-nutrient salt solutions, the concentrations of the cell sap decreased with the decline in density of the solution. It will be apparent that in the case of the $N/50$ solution, the cell sap is 54.4 ohms more concentrated than that of the $N/250$ solution. These results go to confirm the statement already made, that the density of the cell sap and that of the solution tend to exist in equilibrium. In the present case, the plants were obliged to absorb probably the non-nutrient ions, or more of the nutrient elements, in order that there might be an equilibrium between the density of the cell sap and that of the solution.

It seems then from all the preceding experiments, that the assumption originally made, namely, that the density of the cell sap may be proportional to the concentration of the solution in which the plants are growing, is correct, or at least the foregoing data have confirmed it without a *single* exception.

If the original assumption made is wrong, i. e., that there is no appreciable difference in the density of the cell sap of the plants grown in the various concentrations of solution, but that it remains constant as the density of the solution decreases, this suggests at once another way in which the concentration of the cell sap may help to bring about that increased relative transpiration from the highest to the intermediate densities. If the density of the cell sap stayed the same while the concentration of the outside solution diminished, then the osmotic pressure of the former would increase proportionally as compared with that of the latter, and consequently, the pull or attraction for water by the cell sap, and the readiness with which the solution would give it up, would rise in the same ratio. The result would be that the plants in the dilute solution would absorb more water than they could give off, due to the lack of osmotic pressure in the solution to regulate it, and to the greater pull that the cell sap exerts upon it. From this it would appear that the only internal factors which tend to diminish transpiration would be the physical properties of the cell sap, namely, the osmotic pressure, vapor tension, and viscosity.

The last view does not seem to be tenable, not only from the theoretical point of view, but also from the experimental evidence at hand.

If it is true that there is a close relation between the density of the cell sap and that of the outside solution, this would at once suggest the method already described of determining the concentration of the soil solution. Whether it would be a practical way, however, is another question.

The density of the cell sap could be measured by other methods than those employed and described. The most important and probably the most practical ones are these:

1. By the regular plasmolytic method, i. e., determining the point of concentration of the solute at which the cells are plasmolyzed.

2. By growing plants in different densities of solution for a certain length of time and then placing them all in a highly concentrated non-nutrient solution and noting the time they require to wilt. It is assumed here that if the density of the cell sap of the plants grown in the highest concentrated solution is higher than that of the plants grown in the less dense solutions, the plants of the former solutions will resist plasmolysis much longer than those of the latter.

3. By noting the rate of transpiration of plants grown in different densities of solution for a certain length of time and then reversing their position, i. e., placing those grown in the highest concentra-

tions in the lower ones, and vice versa, and again noting the rate of transpiration. In this method it is assumed that if the density of the cell sap of the plants grown in the higher densities of the solution is high, these plants will absorb and transpire water very rapidly when placed in more dilute solutions; and likewise, if the density of the cell sap of the plants grown in the dilute solution is low, these plants will absorb and give off water very slowly when placed in solutions of high concentrations.

The last method was tested experimentally and the results obtained tended to confirm the assumption.

This, in short, is the manner in which the osmotic pressure of the solution and the density of the cell sap may cause the relative transpiration to increase with the decrease in density of the solution down to a certain point. The decrease of the correlative transpiration from this point down, i. e., with the further decrease in density of solution, may be attributed to another factor, namely, to the decreased power of certain densities of solution to stimulate transpiration. It is conceived and assumed here that the lowest density of the nutrient solution has a slight stimulative action upon transpiration, and that it increases with the increase in concentration up to a certain point, beyond which it ceases, or is overcome by the osmotic pressure; or decreases from this point with the diminution in density, just as has already been noted. In other words, the decreased transpiration per unit of growth from the intermediate to the most dilute solution, is ascribed to the reduced stimulative action of the decreased density of solution. To state the same thing in the converse form, the rise in the relative transpiration from the most dilute to the intermediate densities, is due to the greater stimulative action of the increased concentration. The stimulative action cannot continue much further upward than where the change in the curve occurs, because it either reaches its maximum, or it is overcome by other factors, namely, the osmotic pressure of the solution, and the different physical properties of the cell sap.

In what manner the transpiration is stimulated or accelerated by the dilute solutions is not known; it may be chemical or physiological or both.

The whole problem may now be stated in either of the following ways: (1) The transpiration per unit of growth increases with the increase in density of solution, due to the stimulative action of the latter, until a certain concentration is reached and then begins to decrease with a further rise in density, due to the increased osmotic pressure of the latter and to the increased density of the cell sap;

or (2) the relative transpiration increases with the decrease in concentration down to a certain point, due to the reduced osmotic pressure of the diminished densities of solution and to the decreased power of the cell sap to reduce evaporation, and then it begins to decrease with a further decline in density, due to the reduced stimulative action of the latter upon it.

Going back to the original tables (I–III) of solution, sand, and soil cultures, it is very significant to note that while the relative transpiration increases with the rise in density and after a point is reached it decreases, the total dry matter produced increases in all three cultures with the rise in density. In other words, the actual plant growth is proportional to the concentration of the solution. This ratio is certainly remarkable for its regularity, being perfectly constant without any interruption in the curve from the highest to the lowest density in all three cultures.

From these results it appears then that the increase in density or in food supply may bring about simultaneously two phenomena, first, an increase in plant growth, and second, above a certain point, a decrease in total transpiration as the plant growth increases. This knowledge is certainly of the greatest value from the practical point of view, because it suggests another method of conserving the moisture content of those regions where the rainfall is scarce, namely, by increasing the density of the soil solution by the application of soluble food materials. Thereby, the plant growth would be increased, and at the same time, this increase would be produced with a smaller amount of water cost. Furthermore, by increasing the density of the soil solution, the vapor pressure of the latter would be decreased, and therefore, the direct evaporation from the surface of the soil would be reduced. Thus, the application of soluble food materials to the soil would serve three purposes instead of one: (1) Increase the growth of plants, (2) decrease the relative transpiration, (3) diminish the direct evaporation from the surface of the soil.

Mention has been made that the sand and soil cultures were employed, first, to duplicate the solution cultures; and secondly, to see whether the different densities of solution would affect the transpiration of the wheat seedlings in these media in the same order or in the same magnitude as in the water cultures. The table below gives these data.

This table shows the difference in the transpiration per gram of dry matter between solution and sand cultures, and between solution and soil cultures, solution cultures being taken as a standard in both cases. It will be seen that there is a significant difference among these comparisons. Both the sand and soil cultures transpired more per gram of dry matter than the solution culture, and the soil culture transpired the most. The sand and the soil cultures gave off 27.8 and 177.7 grams of water per gram of dry matter respectively more than the solution culture. Evidently, the different densities of solution diminished the magnitude of the transpiration per unit of growth, more than in the sand and soil cultures.

TABLE IX.—*Difference in the Transpiration Per Gram of Dry Matter Among Solution, Sand and Soil Cultures.*

| Density of Solution in p.p.m. | Greater Transpiration Per Gram of Dry Matter in Sand Cultures over Water Cultures. | Greater Transpiration Per Gram of Dry Matter in Soil Cultures over Water Cultures. |
|---|---|---|
| 4,500 | 14.6 | 141.1 |
| 2,250 | 10.7 | 169.2 |
| 750 | 20.0 | 143.7 |
| 375 | 8.9 | 129.2 |
| 187.5 | —10.8 | 146.6 |
| 93.5 | —21.1 | 181.7 |
| 0.0 | 172.6 | 332.1 |
| Average | 27.8 | 177.7 |

One other interesting feature, that may be worked out from Tables I, II and III, is the difference in the dry matter produced between solution and sand cultures, solution and soil cultures, and sand and soil cultures. The table below gives these data.

TABLE X.—*Difference in the Dry Matter Produced Among Solution, Sand and Soil Cultures.*

| Density of Solution in p.p.m. | Greater Growth in Solution Cultures Over Sand Cultures. Grams. | Greater Growth in Solution Cultures Over Soil Cultures. Grams. | Greater Growth in Sand Cultures Over Soil Cultures. Grams. |
|---|---|---|---|
| 4,500 | −.00331 | −.00355 | −.00024 |
| 2,250 | −.00390 | .00071 | .00461 |
| 750 | .00146 | .00658 | .00512 |
| 375 | .00451 | .00683 | .00232 |
| 187.5 | .00435 | .00482 | .00047 |
| 93.5 | .00235 | .00129 | −.00106 |
| 0.0 | −.00152 | −.00255 | −.00103 |
| Average | .00056 | .00206 | .00145 |

These figures show the difference in weight per single plant among the three different cultures. It is very evident that the average dry matter by the solution culture is greater than that of the sand or soil receiving the same densities of solution, and that that of the sand cultures is larger than that of the soil cultures.

The results of the last two tables are certainly interesting, because they indicate the significant phenomena that water cultures produce more dry matter, and at the same time give off less transpiration per unit of growth than the sand or soil culture containing the same densities of solution. Just why there should be such phenomena cannot be explained with certainty, but the following suggestions may be offered. The greater growth in the solution cultures may be due to two causes, namely, (1) to the greater amount of available plant food that the plants have at their disposal, due to the greater volume of the solution; and (2) to the greater ease with which the plants may be able to secure their plant food, due to the fact that it is not absorbed, as it is by the particles in the other two cultures. The smaller correlative transpiration may be due to the same factors as above but in a different way. First, the density of the solution cultures may not become as dilute after the plants have grown for a while, as that of the other two cultures, due to the greater volume and to the frequent renewal of the solution. Secondly, the density of the water cultures is not reduced by absorption, as it is in the sand or soil cultures. Furthermore, the dense layer of molecules and ions that is claimed[32] to be formed by absorption, around the surface of the root system in the solution cultures, may also tend to reduce the relative transpiration and thus help to make it still smaller in this case in comparison with that of the other two cultures.

### *Transpiration of Corn and Bean Seedlings as Affected by Different Densities of a Complete Nutrient Solution, in Water, and Sand Cultures.*

In the preceding series of experiments the transpiration of wheat seedlings as affected by different densities of a complete nutrient solution was studied. It was found that the various concentrations had a very decidedly different effect upon the transpiration of this species of plant. It was now desired to ascertain whether the transpiration of other species of plants would also be affected by the same densities of the complete nutrient solution, and whether this effect would be in the same order as that of wheat. For this purpose two different kinds of plants were chosen, namely, corn and beans, and were grown in solutions and sand cultures containing the same number of concentrations as in the foregoing work. Wheat seedlings were also grown in similar cultures at the same time in order to compare their magnitude of transpiration per unit of growth, with that of the other two species. The seed used in all three cases was of the same variety, and in the case of the wheat and corn it was of pure strains.

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[32] Bot. Gaz. 39: 1–20. 1905.

This line of the investigation involved three solutions and three sand cultures, or one solution and one sand culture for each species. The wheat contained in the solution culture, four bottles with four plants to each bottle, and in the sand culture, four baskets with six plants to each, for each density of solution. The corn had in the solution culture, four bottles containing three plants each, and in the sand cultures, four baskets with four plants to a basket, for each density of solution. The corn contained for both the solution and sand cultures, three bottles and three baskets respectively, with three plants to each receptacle, for each density. Each concentration of solution contained then in the solution culture, 16, 12 and 9; and in the sand culture, 24, 16 and 9 plants of wheat, corn, and beans, respectively.

All the three different species were grown at the same time and under the same conditions for three weeks. Just before they were harvested the following notes were taken on the growth and general appearance of the corn and beans, including the tops in the solution and sand cultures, and the roots in the solution cultures.

The tops of the corn in both the solution and sand cultures, appeared healthy and vigorous, and seemed to increase in growth with the increase in concentration. The color ran from light brown in the highest to dark brown in the lowest density. In the higher density of the solution the middle leaves were almost colorless, while the lower leaves were light brown to light green. As the density decreased, however, the color of the middle leaves became darker.

The corn roots in the water cultures were also very healthy, vigorous, and turgid, and they seemed to increase in growth with the increase of the tops. In no density of solution did they branch very much. The only branching that was observed was near the tops, i. e., close to the seeds. The increase in weight consisted mostly in elongation of the main roots.

The tops of the beans in both the solution and sand cultures, also were healthy and very vigorous. They appeared to have made a slightly uneven growth among the different densities, but they showed the general tendency to increase with the rise in density up to 2,250 p.p.m. and then to diminish again. There were some plants which showed a marked individuality in that they did not grow as rapidly as the others. The color varied from light green in the highest density to dark green in the lowest one.

The roots of the beans in the solution cultures were very healthy, vigorous, and turgid, but there was no great difference in their growth among the different densities. It appeared that their weight was about the same in the various concentrations and that they grew very little after they were placed in the solutions. They were short, thick, and showed few signs of branching.

The tops, after being harvested, were dried and the relative transpiration calculated as in the preceding investigation. Tables XI–XIV, with their accompanying figures (9–12) show the data obtained for the corn and beans.

TABLE XI.—*Effect of Different Densities of a Complete Nutrient Solution Upon the Transpiration Per Gram of Dry Matter of Corn Seedlings Grown in Solution Cultures.*

| Density of Solution in p.p.m. | Grams of Dry Matter Produced. | Grams of Water Transpired. | Grams of Transpiration per Gram of Dry Matter. |
|---|---|---|---|
| 4,500 | 1.1090 | 76.4 | 68.83 |
| 2,250 | 1.0522 | 78.9 | 75.00 |
| 750 | .9600 | 81.6 | 85.01 |
| 375 | .9819 | 78.6 | 80.04 |
| 187.5 | .9122 | 72.4 | 79.37 |
| 93.5 | .8650 | 72.4 | 83.70 |
| 0.0 | .6980 | 63.3 | 90.70 |

TABLE XII.—*Effect of Different Densities of a Complete Nutrient Solution Upon the Transpiration Per Gram of Dry Matter of Corn Seedlings Grown in Sand Cultures.*

| Density of Solution in p.p.m. | Grams of Dry Matter Produced. | Grams of Water Transpired. | Grams of Transpiration per Gram of Dry Matter. |
|---|---|---|---|
| 4,500 | 1.2175 | 84.2 | 69.20 |
| 2,250 | 1.2320 | 113.0 | 91.72 |
| 750 | 1.2170 | 118.4 | 97.30 |
| 375 | 1.1630 | 112.1 | 96.40 |
| 187.5 | .9985 | 97.8 | 97.95 |
| 93.5 | .9930 | 115.0 | 115.08 |
| 0.0 | .9616 | 89.0 | 92.52 |

TABLE XIII.—*Effect of Different Densities of a Complete Nutrient Solution Upon the Transpiration Per Gram of Dry Matter of Bean Seedlings Grown in Solution Cultures.*

| Density of Solution in p.p.m. | Grams of Dry Matter Produced. | Grams of Water Transpired. | Grams of Transpiration per Gram of Dry Matter. |
|---|---|---|---|
| 4,500 | 2.5607 | 173.0 | 67.55 |
| 2,250 | 2.7028 | 187.2 | 69.26 |
| 750 | 2.3720 | 180.3 | 76.00 |
| 375 | 2.2220 | 174.2 | 78.40 |
| 187.5 | 2.0630 | 139.3 | 67.52 |
| 93.5 | 2.0672 | 144.6 | 69.96 |
| 0.0 | 1.9469 | 135.1 | 69.40 |

TABLE XIV.—*Effect of Different Densities of a Complete Nutrient Solution Upon the Transpiration Per Gram of Dry Matter of Bean Seedlings Grown in Sand Cultures.*

| Density of Solution in p.p.m. | Grams of Dry Matter Produced. | Grams of Water Transpired. | Grams of Transpiration per Gram of Dry Matter. |
|---|---|---|---|
| 4,500 | 2.9740 | 249.9 | 84.04 |
| 2,250 | 3.1400 | 265.6 | 84.45 |
| 750 | 2.7094 | 227.4 | 83.91 |
| 375 | 2.1498 | 185.8 | 86.50 |
| 187.5 | 2.2178 | 178.1 | 80.30 |
| 93.5 | 1.9830 | 164.0 | 82.64 |
| 0.0 | 2.1528 | 147.1 | 68.33 |

From an examination of the tables and figures, it becomes very evident that the different densities of the complete nutrient solution also affect the correlative transpiration of the corn and beans, and in practically the same order as that of wheat. It will be seen in almost every table, that the relative transpiration tends to increase with the decrease in density of solution down to a certain point and then it shows a strong tendency to diminish with the further decline in concentration. This is exactly what was found in the case of wheat in the previous series of experiments, the main difference being, that in the latter, the relative transpiration in the dilute solutions was very regular, while in the present experiment, it is somewhat irregular, and consequently, the point or dilution at which the change occurs is not very definite, but it lies somewhere between 0.0 and 375 p.p.m. This irregularity would probably not be noticed had there been a greater number of trials, as evidenced by the preceding line of the investigation. In this latter work, in each individual experiment there was always a tendency for the relative transpiration to be as irregular as the above in the lower densities, but when the average of a large number of series was taken, then it became very consistent.

The probable reason for the tendency of the correlative transpiration to be more or less irregular in the lower densities and not in the higher ones, must be sought in the individuality of the plants, and in the decreased power of the solution and of the cell sap to control transpiration. In the higher densities, the individuality of the plants and the like are probably overshadowed by the greater effects of the osmotic pressure of the solution and of the physical properties of the cell sap upon the transpiration, while in the lower densities, the individuality of the plants and other factors may sometimes predominate over the influences of the solution and of the cell sap and hence there results this irregularity.

Inasmuch as this experiment tends to show, on the whole, that the different densities of the complete nutrient solution affect the correlative transpiration of the corn and beans in practically the same order as that of wheat, the explanations that were suggested for the foregoing line of the investigation may be applicable for the present one as well.

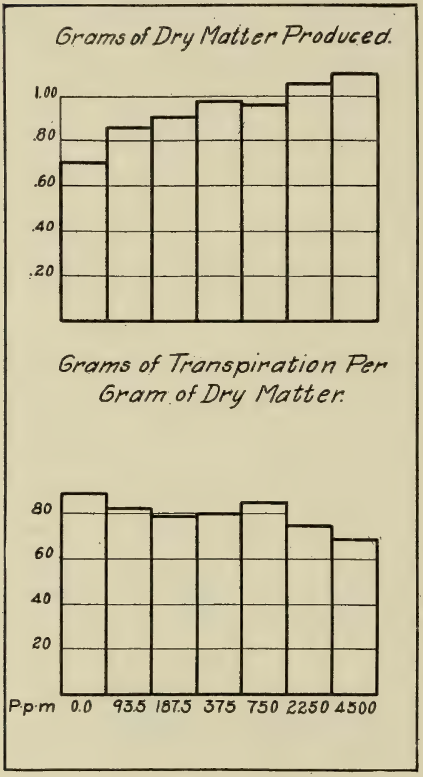

FIG. 9.

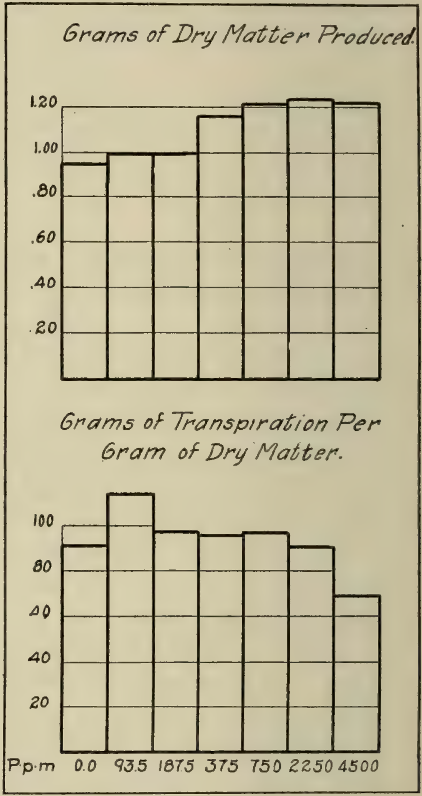

FIG. 10.

FIG. 9.—Effect of different densities of a complete nutrient solution upon the transpiration per gram of dry matter of corn seedlings grown in solution cultures.

FIG. 10.—Effect of different densities of a complete nutrient solution upon the transpiration per gram of dry matter of corn seedlings grown in sand cultures.

It has already been mentioned that in conjunction with the corn and bean series a wheat series was also conducted; the object being to ascertain the actual difference in the amount of transpiration per unit of dry weight, among these different species. The data obtained upon this point are represented in Tables XV and XVI.

These tables show very conclusively that in both the solution and sand cultures, the wheat transpired more water per gram of dry matter than either corn or beans, and that corn transpired more than beans. It will be observed that the differences are very great. In the sand cultures the wheat transpired, on an average, 331.63 grams

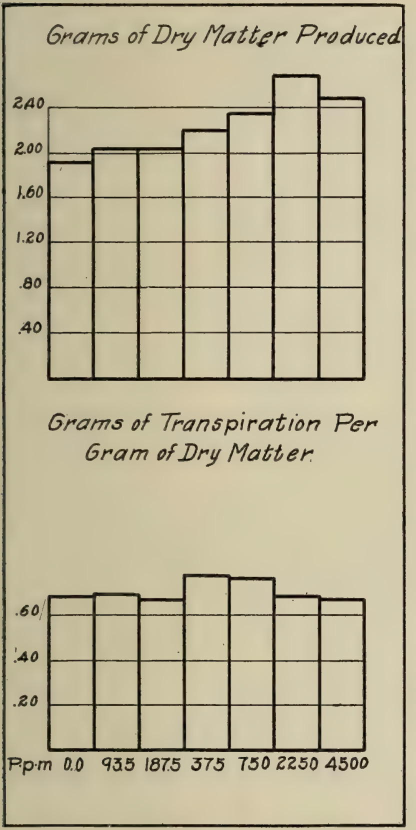

FIG. 11.

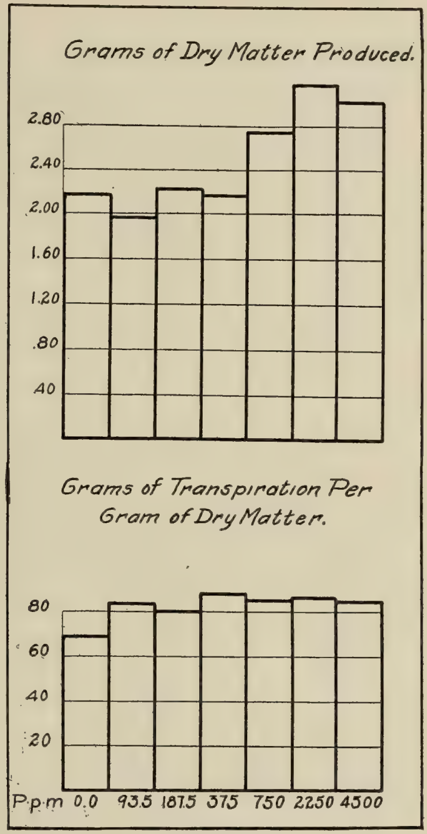

FIG. 12.

FIG. 11.—Effect of different densities of a complete nutrient solution upon the transpiration per gram of dry matter of bean seedlings grown in solution cultures.

FIG. 12.—Effect of different densities of a complete nutrient solution upon the transpiration per gram of dry matter of bean seedlings grown in sand cultures.

of water per gram of dry matter more than the corn; 343.94 grams more than the beans; and the corn 12.30 grams more than the beans. In the solution cultures the order is the same; the wheat used, on an average, 213.27 grams of water per unit of dry weight more than the corn; 221.41 grams more than the beans; and the corn 9.22 grams more than the beans.

Table XV.—*Difference in the Amount of Transpiration Per Gram of Dry Matter Among Wheat, Corn and Bean Seedlings Grown in Sand Cultures.*

| Density of Solution in p.p.m. | Greater Transpiration per Gram of Dry Matter of Wheat Over Corn. | Greater Transpiration per Gram of Dry Matter of Wheat Over Beans. | Greater Transpiration per Gram of Dry Matter of Corn Over Beans. |
|---|---|---|---|
| 4,500 | 266.30 | 251.46 | −14.84 |
| 2,250 | 296.18 | 303.45 | 7.27 |
| 750 | 341.00 | 354.39 | 13.39 |
| 375 | 354.00 | 363.90 | 9.90 |
| 187.5 | 373.55 | 391.20 | 17.65 |
| 93.5 | 328.42 | 360.86 | 32.44 |
| 0.0 | 361.98 | 386.17 | 24.19 |
| Average | 331.63 | 344.49 | 12.85 |

Table XVI.—*Difference in the Amount of Transpiration Per Gram of Dry Matter Among Wheat, Corn and Bean Seedlings Grown in Solution Cultures.*

| Density of Solution in p.p.m. | Greater Transpiration per Gram of Dry Matter of Wheat Over Corn. | Greater Transpiration per Gram of Dry Matter of Wheat Over Beans. | Greater Transpiration per Gram of Dry Matter of Corn Over Beans. |
|---|---|---|---|
| 4,500 | 201.80 | 202.55 | 1.28 |
| 2,250 | 229.00 | 234.74 | 5.74 |
| 750.0 | 215.69 | 224.70 | 9.01 |
| 375.0 | 253.96 | 255.60 | 1.64 |
| 187.0 | 256.63 | 268.48 | 11.85 |
| 93.5 | 263.50 | 277.24 | 13.74 |
| 0.0 | 65.30 | 86.60 | 21.30 |
| Average | 212.27 | 221.41 | 9.22 |

These results are in agreement with those found by other investigators. While no experimenter used exactly the same plants, the work of Lawes and Gilbert and Hellriegel, however, show that wheat transpired more per unit of dry substance than beans, while the results of King and Wollny show that the corn requires a great deal less water per unit of dry substance than any other cultivated crop they worked with.

The other interesting features that are illustrated by the original tables of transpiration of corn and beans are the differences in the transpiration per gram of dry matter between the solution and sand cultures. These data are given in Tables XVII and XVIII.

TABLE XVII.—*Difference in the Amount of Transpiration Per Gram of Dry Matter of Corn Between the Solution and Sand Cultures.*

| Density of Solution in p.p.m. | Transpiration per Gram of Dry Matter of Corn in Solution Cultures. | Transpiration per Gram of Dry Matter of Corn in Sand Cultures. | Greater Transpiration per Gram of Dry Matter of Sand Over Solution Cultures. |
|---|---|---|---|
| 4,500 | 68.83 | 69.20 | .37 |
| 2,250 | 75.00 | 91.72 | 16.72 |
| 750 | 85.01 | 97.30 | 12.29 |
| 375 | 80.04 | 96.40 | 16.36 |
| 187.5 | 79.34 | 97.95 | 18.58 |
| 93.5 | 83.70 | 115.08 | 31.38 |
| 0.0 | 90.70 | 92.52 | 1.82 |
| Average | | | 13.93 |

TABLE XVIII.—*Difference in the Amount of Transpiration Per Gram of Dry Matter of Beans Between the Solution and Sand Cultures.*

| Density of Solution in p.p.m. | Transpiration per Gram of Dry Matter of Beans in Solution Cultures. | Transpiration per Gram of Dry Matter of Beans in Sand Cultures. | Greater Transpiration per Gram of Dry Matter of Sand Over Solution Cultures. |
|---|---|---|---|
| 4,500 | 67.55 | 84.04 | 16.49 |
| 2,250 | 69.26 | 84.45 | 15.19 |
| 750 | 76.00 | 83.91 | 7.91 |
| 375 | 78.40 | 86.50 | 8.10 |
| 187.5 | 67.52 | 80.30 | 12.78 |
| 93.5 | 69.96 | 82.64 | 12.68 |
| 0.0 | 69.40 | 68.33 | −1.07 |
| Average | | | 10.30 |

It is very apparent from these tables that the transpiration per unit of growth of both the corn and the beans is much greater in the sand than in the solution cultures. It will be noticed that the corn transpired, on an average, 13.93 grams and the beans 10.85 grams more water per gram of dry matter in the sand, than in the solution cultures. These results are in perfect agreement with those of wheat, and they all go to show that these three plants grew with a greater economy of water in the solution than in the sand cultures.

In connection with the above data, might also be mentioned the difference in the amount of actual growth of these two crops, in the two different cultures. As will be remembered, it was found in the case of wheat that the solution cultures produced a greater actual dry matter than the sand cultures. The present experiment shows the same thing in the case of corn, but not so in the case of the beans. The data are given herewith in Tables XIX and XX.

As already stated, these figures indicate that, in the case of corn, the solution cultures produced a greater yield of dry matter than the sand cultures, the greater average increase being .00898 gram;

while in the case of the beans, it was the sand cultures that gave the greater growth, the greater average yield being .2070 gram.

TABLE XIX.—*Difference in the Growth of Corn Between Solution and Sand Cultures.*

| Density of Solution in p.p.m. | Average Weight per Single Plant in Solution Cultures. Grams. | Average Weight per Single Plant in Sand Cultures. Grams. | Greater Growth in Solution Over Sand Cultures. Grams. |
|---|---|---|---|
| 4,500 | .09243 | .07606 | .01637 |
| 2,250 | .08768 | .07700 | .01068 |
| 750 | .08000 | .07606 | .00394 |
| 375 | .08184 | .07270 | .00914 |
| 187.5 | .07600 | .06238 | .01362 |
| 93.5 | .07209 | .06206 | .01003 |
| 0.0 | .05816 | .06006 | —.00090 |
| Average | | | .00898 |

TABLE XX.—*Difference in the Growth of Beans Between Solution and Sand Cultures.*

| Density of Solution in p.p.m. | Total Weight of Plants in Solution Cultures. Grams. | Total Weight of Plants in Sand Cultures. Grams. | Greater Growth in Solution Over Sand Cultures. Grams. |
|---|---|---|---|
| 4,500 | 2.5607 | 2.9740 | —.4133 |
| 2,250 | 2.7028 | 3.1400 | —.4372 |
| 750 | 2.3720 | 2.7090 | —.3370 |
| 375 | 2.2220 | 2.1498 | .0722 |
| 187.5 | 2.0630 | 2.2178 | —.1548 |
| 93.5 | 2.0672 | 1.8960 | .1712 |
| 0.0 | 1.9469 | 2.1528 | —.2059 |
| Average | | | —.2070 |

### *Transpiration of Wheat Seedlings as Affected by Different Densities of Non-Nutrient Solutions, in Water and Sand Cultures.*

It has been seen in the foregoing lines of the investigation that the different densities of the complete nutrient solution had a significantly different effect upon the transpiration of wheat as well as upon that of corn and beans. It was shown that in all three plants the transpiration per gram of dry matter tended to increase with the decrease in density down to a certain point and then to diminish with the further lowering in concentration. The question now arises whether similar densities of a non-nutrient solution would also affect the transpiration of these plants, and especially that of wheat, and whether this effect would be in the same order as that of the complete nutrient solution. To investigate this question two different non-nutrient solutions, namely, NaCl and $Na_2SO_4$ were prepared, each having the same number of densities as the full nutrient solution. Each density was of about the same strength as the corresponding one in the nutrient solution, and to each one of these densities was added exactly the same amount of the complete nutrient solution in order that the plants might make a normal growth. In this manner, the density of the non-nutrient solution was varied, while the amount of the nutrient solution was kept constant.

The stock solutions of the NaCl and $Na_2SO_4$ were prepared by dissolving 45 grams of each salt in 10 liters of distilled water, thus making each one of them of the same strength as the stock solution of the complete nutrient. The different densities of the solutions which were needed for the experiment were then prepared in the manner shown below.

*Plan of Preparing the Different Densities of the NaCl Solution.*

| No. c.c. of NaCl. | No. c.c. of $H_2O$. | No. c.c. of Nutrient Solution. | Total Volume of Solution. | Density of NaCl Solution in p.p.m. | Resistance of Final Solution in Ohms. |
|---|---|---|---|---|---|
| 3,000.0 | 0.0 | 50 | 3,050 | 4,500 | 50.3 |
| 1,500.0 | 1,500.0 | 50 | 3,050 | 2,250 | 103.8 |
| 500.0 | 2,500.0 | 50 | 3,050 | 750 | 195.5 |
| 250.0 | 2,750.0 | 50 | 3,050 | 375 | 336.0 |
| 125.0 | 2,875.0 | 50 | 3,050 | 187.5 | 672.1 |
| 50.0 | 2,950.0 | 50 | 3,050 | 93.5 | 1,099.8 |
| 0.0 | 3,000.0 | 50 | 3,050 | 0.0 | 2,775.0 |

*Plan of Preparing the Different Densities of the $Na_2SO_4$ Solution.*

| No. c.c. of $Na_2SO_4$ Solution. | No. c.c. of $H_2O$. | No. c.c. of Nutrient Solution. | Total Volume of Solution. | Density of $Na_2SO_4$ Solution in p.p.m. | Resistance of Final Solutions in Ohms. |
|---|---|---|---|---|---|
| 3,000.0 | 0.0 | 50 | 3,050 | 4,500 | 78.2 |
| 1,500.0 | 1,500.0 | 50 | 3,050 | 2,250 | 132.5 |
| 500.0 | 2,500.0 | 50 | 3,050 | 750 | 311.5 |
| 250.0 | 2,750.0 | 50 | 3,050 | 375 | 473.5 |
| 125.0 | 2,875.0 | 50 | 3,050 | 187.5 | 761.3 |
| 50.0 | 2,150.0 | 50 | 3,050 | 93.5 | 1,361.8 |
| 0.0 | 3,000.0 | 50 | 3,050 | 0.0 | 2,775.0 |

Attention must be called to the fact that the density in parts per million as shown in the above tables is not the density of the final solutions, i. e., the non-nutrient plus the nutrient but only that of the non-nutrient salt solutions. The density of the final solutions must be slightly higher on account of the addition of the 50 c.c. of the complete nutrient solution which had a density of 4,500 p.p.m. These concentrations must therefore be slightly higher than the corresponding ones in the complete nutrient solution as used in the preceding experiments.

The effect of the different densities of both of these non-nutrient salt solutions upon the relative transpirations of the wheat seedlings, was studied in cultures similar to those of the various concentrations of the complete nutrient solution, namely, in solution and sand cultures. The quartz cultures comprised two sizes of sand. The solution cultures contained for each density four bottles with four plants in each, and the sand cultures, three baskets with five plants in each.

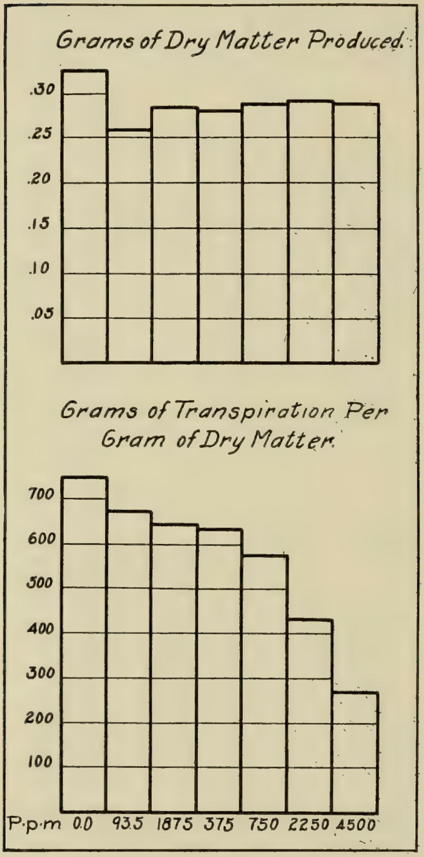

FIG. 13.

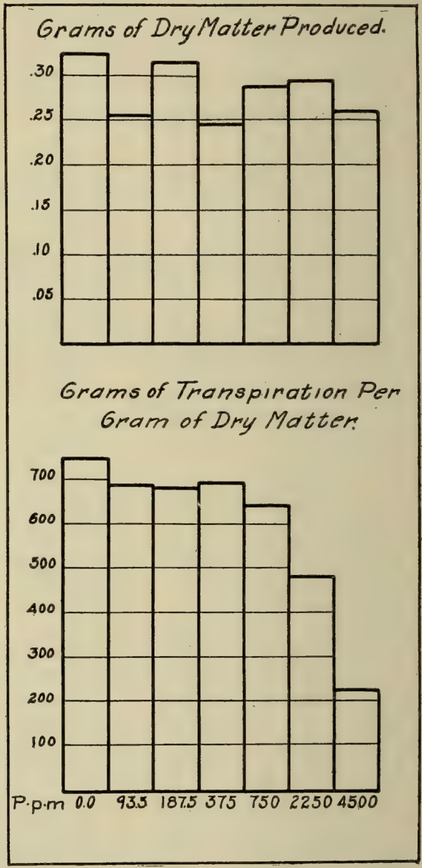

FIG. 14.

FIG. 13.—Effect of different densities of NaCl upon the transpiration per gram of dry matter of wheat seedlings grown in solution cultures.

FIG. 14.—Effect of different densities of $Na_2SO_4$ upon the transpiration per gram of dry matter of wheat seedlings grown in solution cultures.

Both kinds of cultures for both salt solutions were conducted at the same time for three weeks. At the end of this period the following notes were taken on the growth and general appearance of the plants.

The tops in both the solution and sand cultures for both salts were healthy and vigorous, and appeared to have made the largest growth in the intermedite densities. The color varied from dark green in the highest to light green in the lowest density.

The tops in the water and sand cultures of the NaCl showed a slightly greater growth than those of the corresponding cultures in

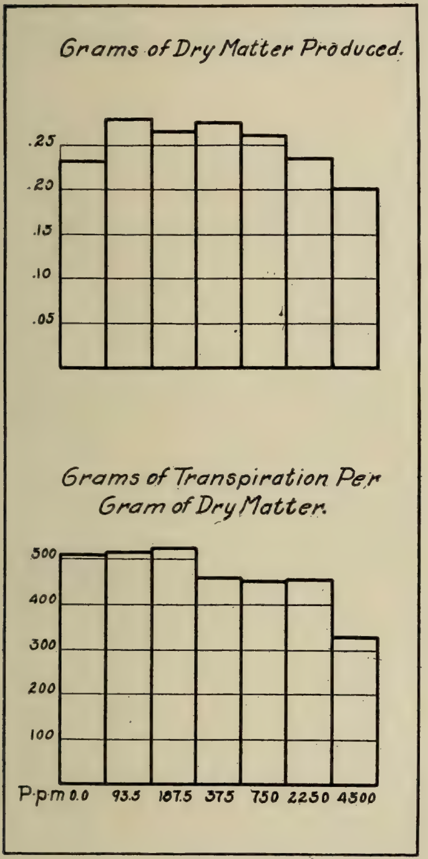

FIG. 15.

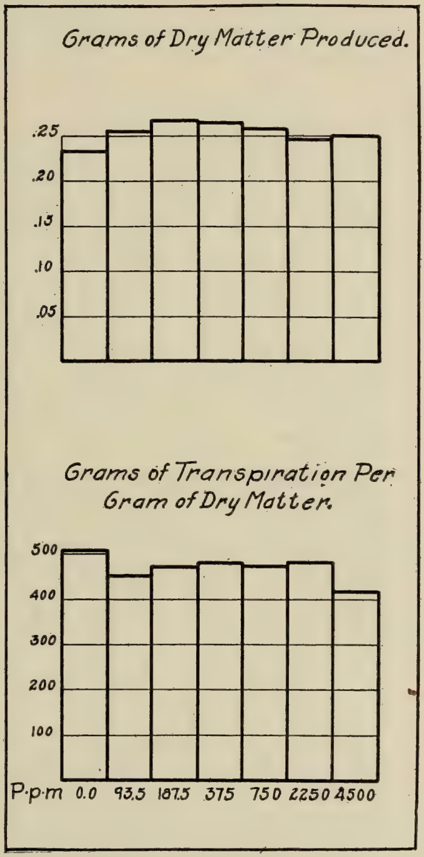

FIG. 16.

FIG. 15.—Effect of different densities of NaCl upon the transpiration per gram or dry matter of wheat seedlings grown in sand cultures. Average of two series.

FIG. 16.—Effect of different densities of $Na_2SO_4$ upon the transpiration per gram of dry matter of wheat seedlings grown in sand cultures. Averages of two series.

$Na_2SO_4$. The tops of the solution cultures of both non-nutrient salts were larger than those of the sand cultures.

The roots in the solution cultures of both salt solutions were very small and unhealthy in the two highest densities, but in the other concentrations they were healthy, vigorous, and turgid, and appeared to be larger in the intermediate densities.

The final data for this part of the investigation were procured similarly to those of the preceding experiments. The following tables (XXI–XXIV) with their graphical representations (Figs. 13–16) show the individual results of the solution cultures, and the average results of the two sizes of the sand cultures.

TABLE XXI.—*Effect of Different Densities of NaCl Upon the Transpiration Per Gram of Dry Matter of Wheat Seedlings Grown in Solution Cultures.*

| Density of NaCl in p.p.m. | Grams of Dry Matter Produced. | Grams of Water Transpired. | Grams of Transpiration per Gram of Dry Matter. |
|---|---|---|---|
| 4,500.0 | .2850 | 76.10 | 267.0 |
| 2,250.0 | .2917 | 124.70 | 427.5 |
| 750.0 | .2846 | 160.80 | 565.0 |
| 375.0 | .2807 | 175.50 | 625.2 |
| 187.5 | .2824 | 179.70 | 636.4 |
| 93.5 | .2573 | 171.80 | 667.6 |
| 0.0 | .3242 | 240.10 | 740.4 |

TABLE XXII.—*Effect of Different Densities of $Na_2SO_4$ Upon the Transpiration Per Gram of Dry Matter of Wheat Seedlings Grown in Solution Cultures.*

| Density of $Na_2SO_4$ in p.p.m. | Grams of Dry Matter Produced. | Grams of Water Transpired. | Grams of Transpiration per Gram of Dry Matter. |
|---|---|---|---|
| 4,500.0 | .2590 | 57.80 | 223.2 |
| 2,250.0 | .2918 | 139.90 | 479.4 |
| 750.0 | .2885 | 182.90 | 634.0 |
| 375.0 | .2447 | 168.70 | 689.4 |
| 187.5 | .3166 | 215.20 | 679.7 |
| 93.5 | .2522 | 173.30 | 687.2 |
| 0.0 | .3242 | 240.10 | 740.4 |

TABLE XXIII.—*Effect of Different Densities of NaCl Upon the Transpiration Per Gram of Dry Matter of Wheat Seedlings Grown in Sand Cultures. Averages of Two Series.*

| Density of NaCl in p.p.m. | Grams of Dry Matter Produced. | Grams of Water Transpired. | Grams of Transpiration per Gram of Dry Matter. |
|---|---|---|---|
| 4,500.0 | .2396 | 78.5 | 325.6 |
| 2,250.0 | .2375 | 107.0 | 450.8 |
| 750.0 | .2593 | 116.0 | 450.3 |
| 375.0 | .2744 | 125.9 | 458.6 |
| 187.5 | .2637 | 137.8 | 523.0 |
| 93.5 | .2759 | 141.1 | 512.7 |
| 0.0 | .2325 | 118.5 | 511.0 |

TABLE XXIV.—*Effect of Different Densities of $Na_2SO_4$ Upon the Transpiration Per Gram of Dry Matter of Wheat Seedlings Grown in sand Cultures. Averages of Two Series.*

| Density of $Na_2SO_4$ in p.p.m. | Grams of Dry Matter Produced. | Grams of Water Transpired. | Grams of Transpiration per Gram of Dry Matter. |
|---|---|---|---|
| 4,500.0 | .2517 | 105.8 | 419.5 |
| 2,250.0 | .2446 | 117.8 | 482.1 |
| 750.0 | .2572 | 121.2 | 471.9 |
| 375.0 | .2681 | 128.0 | 477.5 |
| 187.5 | .2688 | 126.2 | 470.5 |
| 93.5 | .2543 | 114.0 | 449.9 |
| 0.0 | .2325 | 118.5 | 511.0 |

The main facts presented by the figures of these tables may be stated thus: The transpiration per gram of dry matter of the wheat seedlings increased quite regularly in the water cultures of both the non-nutrient salts, from the highest to the lowest density; in the sand cultures of the NaCl it increased from the highest concentration to that of 375 p.p.m. and then diminished with the further decrease in density; in the sand cultures of the $Na_2SO_4$ it was somewhat irregular but it showed a tendency to increase also from the highest density to that of 375 p.p.m. and then to decline with the further dilution.

From these facts it is evident that the different densities of the nonnurient salt solutions also affect the relative transpiration of the wheat and that this effect is in practically the same order as that of the various concentrations of the complete nutrient solution. It is exactly the same in the higher densities of all the different cultures, practically the same in all the concentrations of both sand cultures, but not quite the same in the lower densities of the solution cultures. In the latter there is no strong tendency for the transpiration in decline in the greater dilutions.

Attention must be called to the fact that the very marked diminution in the relative transpiration in the two highest densities in both solution cultures is believed to be due not wholly to the density, but also to the condition of the roots in these solutions. It will be remembered from the description that the roots in these densities were small, flaccid and unhealthy. The writer is convinced of the fact that such conditions tended to reduce the absorption of water and indirectly reduced the total transpiration.

A most striking feature to be noticed from the preceding tables and Figs. 13–16 is the peculiar general run of the total growth among the different densities. It will be remembered that in the case of the complete nutrient solution, this increased directly with the increase in concentration. In these non-nutrient solutions, however, it made the greatest increase in the intermediate densities. That is to say, the greatest actual growth occurred in the intermediate concentrations. There are some exceptions but these may be considered as abnormalities as the general tendency is for the maximum growth to center around the intermediate densities. This fact is very significant because it tends to confirm the general statement[33] that toxic or non-nutrient chemical salts such as here used, when employed in rather concentrated forms, are fatal to plant growth; when in very small traces are neutral; but when in intermediate quantities are very beneficial in that they stimulate growth.

Another fact that is brought out very markedly by these same tables is the difference in the transpiration per unit of growth between the solution and sand cultures of both non-nutrient salts The data are given herewith in Tables XXV and XXVI.

TABLE XXV.—*Difference in the Amount of Transpiration Per Gram of Dry Matter of Wheat Seedlings Between Solution and Sand Cultures of NaCl.*

| Density of NaCl in p.p.m. | Transpiration per Gram of Dry Matter of Solution Cultures. | Transpiration per Gram of Dry Matter of Sand Cultures. | Greater Transpiration per Gram of Dry Matter of Solution Over Sand Cultures. |
|---|---|---|---|
| 4,500 | 267.0 | 325.6 | − 58.6 |
| 2,250 | 427.5 | 450.8 | − 23.3 |
| 750 | 565.0 | 450.3 | 114.7 |
| 375 | 625.2 | 458.6 | 166.6 |
| 187.5 | 636.4 | 523.0 | 113.4 |
| 93.5 | 667.6 | 512.7 | 154.9 |
| 0.0 | 740.5 | 511.0 | 229.5 |
| Average | | | 99.4 |

TABLE XXVI.—*Difference in the Amount of Transpiration Per Gram of Dry Matter of Wheat Seedlings Between Solution and Sand Cultures of* $Na_2SO_4$

| Density of $Na_2SO_4$ in p.p.m. | Transpiration per Gram of Dry Matter of Solution Cultures. | Transpiration per Gram of Dry Matter of Sand Cultures. | Greater Transpiration per Gram of Dry Matter of Solution Over Sand Cultures. |
|---|---|---|---|
| 4,500 | 223.2 | 419.5 | −196.3 |
| 2,250 | 479.4 | 482.1 | − 2.7 |
| 750 | 634.0 | 471.9 | 162.1 |
| 375 | 689.4 | 477.5 | 211.9 |
| 187.5 | 679.7 | 470.5 | 209.2 |
| 93.0 | 687.2 | 449.9 | 238.0 |
| 0.0 | 740.4 | 511.0 | 229.4 |
| Average | | | 121.6 |

These tables show that the amount of transpiration per gram of dry matter is greater in the solution than in the sand cultures, being on an average 99.4 grams greater in the NaCl, and 121.6 grams in the $Na_2SO_4$. This is evidently just the opposite from that which was found in the case of the complete nutrient solutions with wheat, corn, and beans.

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[33] Bot. Gaz. 39: 1–20. 1905.

It is interesting to note that in the two highest densities of both the non-nutrient salts, the relative transpiration is larger in the sand cultures, while in all the other concentrations it is greater in the solution cultures.

The other interesting fact that is shown in Tables XXI, XXII, XXIII, and XXIV, is the difference in the actual growth between the solution and sand cultures. It will be remembered that in all the preceding experiments it was found that the solution cultures gave a larger growth than the sand cultures. The same thing is true in the present experiment, as will be seen in Tables XXVII and XXVIII.

TABLE XXVII.—*Difference in Actual Plant Growth Between Solution and Sand Cultures in NaCl.*

| Density of NaCl in p.p.m. | Average Weight per Single Plant in Solution Cultures. | Average Weight per Single Plant in Sand Cultures. | Greater Growth in Solution Over Sand Culture. |
|---|---|---|---|
| 4,500 | .02375 | .01597 | .00778 |
| 2,250 | .02431 | .01583 | .00848 |
| 750 | .02372 | .01728 | .00644 |
| 375 | .02339 | .01829 | .00510 |
| 187.5 | .02353 | .01758 | .00595 |
| 93.5 | .02144 | .01839 | .00305 |
| 0.0 | .02702 | .01550 | .01152 |
| Average | | | .00690 |

TABLE XXVIII.—*Difference in Actual Plant Growth Between Solution and Sand Cultures in* $Na_2SO_4$.

| Density of $Na_2SO_4$ in p.p.m. | Average Weight per Single Plant in Solution Cultures. | Average Weight per Single Plant in Sand Cultures. | Greater Growth in Solution Over Sand Cultures. |
|---|---|---|---|
| 4,500 | .02158 | .01678 | .00480 |
| 2,250 | .02432 | .01631 | .00801 |
| 750 | .02404 | .01715 | .00689 |
| 375 | .02039 | .01787 | .00252 |
| 187.5 | .02638 | .01792 | .00846 |
| 93.5 | .02102 | .01695 | .00407 |
| 0.0 | .02702 | .01550 | .01152 |
| Average | | | .00661 |

These figures show very conclusively that the actual dry matter produced is greater in the solution than in the sand cultures, being on an average .00690 gram per single plant, larger in the case of the NaCl, and .00661 gram greater in the case of the $Na_2SO_4$.

## *Wheat Seedlings as Affected by Different Densities of an Organic Substance, in Water Cultures.*

In connection with the foregoing studies an experiment was conducted to determine the effect of different densities of an organic substance upon the transpiration of the wheat seedlings. The organic substance used was agar. Its stock solution was prepared by dissolving a known quantity of the solid material in boiling distilled water, then brought up to a definite volume, and the different densities prepared from this. The number of concentrations employed was three, namely, 1.5, 1, and 0.5 grams per two liters of solution respectively. To each one of these densities was added 50 c.c. of a complete nutrient solution having a density of 4,500 p.p.m. As a check for comparison distilled water was used which also contained 50 c.c. of the nutrient solution in two liters.

This experiment comprised only water cultures. Each concentration contained three bottles with four plants in each. The total number of plants for each density was, therefore, 12. These plants were allowed to grow three weeks; they were then harvested, the dry weight of the tops determined and the correlative transpiration calculated. The results obtained are given herewith in Table XXIX.

TABLE XXIX.—*Effect of Different Densities of an Organic Substance Upon the Transpiration Per Gram of Dry Matter of the Wheat Seedlings Grown in Solution Cultures.*

| Density of Solution in Grams in 2 Liters. | Grams of Dry Matter Produced. | Grams of Water Transpired. | Grams of Transpiration per Gram of Dry Matter. |
|---|---|---|---|
| 1.5 | .4410 | 330.5 | 749.4 |
| 1.0 | .4276 | 322.2 | 756.1 |
| 0.5 | .3707 | 283.5 | 764.8 |
| Check | .3590 | 315.6 | 879.0 |

These figures show very conclusively that the transpiration per gram of dry matter increases with the decrease in density also in the organic substance. It will be seen that the increase is quite gradual and very regular from the highest density to the check, and the differences between the former and the latter are very marked.

## *Transpiration of Wheat Seedlings as Affected by Different Quantities of Various Chemical Salts.*

The object of this experiment was to determine the specific effect of different quantities of various chemical plant nutrient salts upon the transpiration per gram of dry matter of the wheat seedlings.

It was desired to ascertain here whether by varying the amounts of certain chemical plant nutrient compounds, the correlative transpiration would vary, either directly or inversely with the density. For this purpose three of the most important plant food constituents were used, namely, N, K, and P in the forms of $Ca(NO_3)_2$, KCl and $Na_2HPO_4$ respectively. Their amounts were varied in a complete nutrient solution by one half. That is to say, in a full nutrient solution of a standard formula, each one of these salts was used at the full rate and also at one half the rate. For instance, the standard formula of the complete nutrient solution in 20 liters of water was the following:

| | Grams. |
|---|---|
| $Ca(NO_3)_2$ | 27.0 |
| $MgSO_4$ | 6.0 |
| $Na_2HPO_4$ | 15.0 |
| $Fe_2(SO_4)_3$ | 0.5 |
| KCl | 7.5 |

but this standard solution was prepared also in such a manner that the salt of which the quantity was to be varied would be only half as much in weight as is represented above. For example, in the case of the $Ca(NO_3)_2$ the solution would be so prepared as to contain only 13.5 grams of this salt for the one half quantity, and 27.0 grams as shown above, for the full amount. In similar manner it would be made up to contain the different quantities of the other two salts. In this way, each salt would be present either in one half or in full quantity, while all the other salts would be in the amounts called for by the standard formula.

The effect of the different quantities of all these three salts upon the correlative transpiration, was studied both in the solution and in the sand cultures. In each quantity or density of each salt there were twelve plants in the case of the solution cultures, and fifteen plants in the case of the sand cultures. These plants were allowed to grow for three weeks. At the time they were harvested they looked very healthy, and they appeared to have made an excellent development. The tops were dried, weighed, and the correlative transpiration determined. The following tables, XXX to XXXII, contain these data.

Table XXXII contains the transpiration per gram of dry matter of Tables XXX and XXXI representing the solution and sand cultures respectively. It will be seen that with the exception of the KCl both cultures agree perfectly and show that in the case of the $Ca(NO_3)_2$

the usual quantity gave less transpiration per gram of dry matter than the half quantity, while in the case of the $Na_2HPO_4$ the reverse was true, the full amount caused a greater correlative transpiration than the half quantity. The KCl shows that in the sand culture the normal amount diminished the relative transpiration more than the half amount, while in the solution culture the opposite was true. These results go to indicate that the increased density of the $Ca(NO_3)_2$ retarded the correlative transpiration, that of the $Na_2HPO_4$ accelerated it, while that of the KCl retarded it in the sand culture but accelerated it in the solution culture.

TABLE XXX.—*Transpiration of Wheat Seedlings as Affected by Varying the Amount of N, K, and P in a Complete Nutrient Solution.*
*Solution Cultures.*

| Name and Quantity of Salt. | Density of Solution in Ohms. | Grams of Dry Matter Produced | Grams of Water Transpired. | Grams of Transpiration per Gram of Dry Matter. |
|---|---|---|---|---|
| ½ $Ca(NO_3)_2$ . . . . . | 162.68 | .5278 | 268.10 | 508.0 |
| 1 $Ca(NO_3)_2$ . . . . . | 85.32 | .5072 | 238.20 | 469.7 |
| ½ KCL . . . . . . . . . | 143.10 | .6135 | 286.00 | 466.2 |
| 1 KCl . . . . . . . . . . | 103.27 | .4924 | 234.10 | 475.4 |
| ½ $Na_2HPO_4$ . . . . . | 126.00 | .6458 | 288.90 | 447.4 |
| 1 $Na_2HFO_4$ . . . . . | 117.70 | .4880 | 246.50 | 505.1 |

TABLE XXXI.—*Transpiration of Wheat Seedlings as Affected by Varying the Amount of N, K, and P in a Complete Nutrient Solution.*
*Sand Cultures.*

| Name and Quantity of Salt. | Density of Solution in Ohms. | Grams of Dry Matter Produced. | Grams of Water Transpired. | Grams of Transpiration per Gram of Dry Matter. |
|---|---|---|---|---|
| ½ $Ca(NO_3)_2$ . . . . . | 162.68 | .6983 | 323.80 | 463.7 |
| 1 $Ca(NO_3)_2$ . . . . . | 85.32 | .9478 | 408.50 | 431.0 |
| ½ KCl . . . . . . . . . | 143.10 | .8348 | 377.50 | 452.2 |
| 1 KCl . . . . . . . . . | 103.27 | .8938 | 374.40 | 418.9 |
| ½ $Na_2HPO_4$ . . . . . | 126.00 | .8666 | 355.60 | 410.4 |
| 1 $Na_2HPO_4$ . . . . . | 117.00 | .8651 | 379.10 | 438.2 |

TABLE XXXII.—*Transpiration of Wheat Seedlings as Affected by Varying the Amount of N, K, and P in a Complete Nutrient Solution.*
*Solution and Sand Cultures.*

| Name and Quantity of Salt. | Density of Solution in Ohms. | Grams of Transpiration per Gram of Dry Matter in Solution Cultures. | Grams of Transpiration per Gram of Dry Matter in Sand Cultures. |
|---|---|---|---|
| ½ $Ca(NO_3)_2$ . . . . . . . . . . | 162.68 | 508.0 | 463.7 |
| 1 $Ca(NO_3)_2$ . . . . . . . . . . | 85.32 | 469.7 | 431.0 |
| ½ KCl . . . . . . . . . . . . . . . | 143.10 | 466.2 | 452.2 |
| 1 KCl . . . . . . . . . . . . . . . | 103.27 | 475.4 | 418.9 |
| ½ $Na_2HPO_4$ . . . . . . . . . . | 126.00 | 447.4 | 410.4 |
| 1 $Na_2HPO_4$ . . . . . . . . . . | 117.00 | 505.1 | 438.2 |

These results agree in the main with those of Reed. As will be remembered this investigator found that salts which possessed the $NO_3$ and K ions always tended to retard transpiration, while the salts which contained the $PO_4$ ion always showed an accelerating effect.

The accelerating action of the salts containing the $PO_4$ ion upon the correlative transpiration appears to be conclusive, not only from the above evidence, but also from the data that will be shown in a further experiment. This fact is indeed very significant because it tends not only to confirm the hypothesis of stimulation as already suggested, but also suggests that the different chemical salts may have a different specific action upon the correlative transpiration; some may tend to inhibit it more than others. Indeed such appear to be the facts, as will be shown in the subsequent experiments.

Regarding the difference in the transpiration per gram of dry matter and also the actual growth, between the solution and sand cultures, this experiment disagrees most decidedly with most of the preceding ones upon these two points. This experiment shows, as will be seen from the following tables, that the correlative transpiration is greater in the solution than in the sand cultures, while the actual growth is greater in the latter than in the former. The data for both cases are given herewith in Tables XXXIII and XXXIV.

TABLE XXXIII.—*Difference in the Amount of Transpiration Per Gram of Dry Matter Between Solution and Sand Cultures.*

| Name and Quantity of Salt. | Grams of Transpiration per Gram of Dry Matter in Solution Cultures. | Grams of Transpiration per Gram of Dry Matter in Sand Cultures. | Greater Correlative Transpiration in Solution Cultures. |
|---|---|---|---|
| ½ $Ca(NO_3)_2$.. | 508 | 463.7 | 44.3 |
| 1 $Ca(NO_3)_2$.. | 469.7 | 431.0 | 38.7 |
| ½ KCl...... | 466.2 | 452.2 | 14.0 |
| 1 KCl...... | 475.4 | 418.9 | 56.5 |
| ½ $Na_2HPO_4$.. | 475.4 | 410.4 | 37.0 |
| 1 $Na_2HPO_4$.. | 447.4 | 438.2 | 66.9 |
| Average .. | | | 42.9 |

TABLE XXXIV.—*Difference in the Actual Dry Matter Produced Between the Solution and Sand Cultures.*

| Name and Quantity of Salt. | Average Weight per Single Plant in Solution Cultures. Grams. | Average Weight per Single Plant in Sand Cultures. Grams. | Greater Dry Matter in Sand Cultures. Grams. |
|---|---|---|---|
| ½ $Ca(NO_3)_2$.. | .04397 | .04655 | .00258 |
| 1 $Ca(NO_3)_2$.. | .04227 | .06320 | .02093 |
| ½ KCl...... | .05113 | .05566 | .00453 |
| 1 KCl...... | .04104 | .05955 | .01851 |
| ½ $Na_2HPO_4$.. | .05382 | .05777 | .00395 |
| 1 $Na_2HPO_4$.. | .04067 | .05767 | .01700 |
| Average .. | | | .01125 |

Table XXXIII contains the difference in the amount of correlative transpiration, and Table XXXIV the difference in the actual plant growth, between the solution and sand cultures. It will be observed in the former, that the solution cultures transpired 42.9 grams of water per gram of dry matter more than the sand cultures, while in the latter the sand cultures produced on an average .01125 gram per single plant more dry matter than the solution cultures.

Evidently both these cases are at a variance with the corresponding ones in most of the preceding experiments, and consequently are exceptions to the effect of the factors suggested to account for them.

### *Transpiration of Wheat Seedlings as Affected by Different Chemical Salts and by the Ions of these Salts in Water and Sand Cultures.*

In the last experiment an attempt was made to study the specific action of different amounts of $Ca(NO_3)_2$, $KCl$ and $Na_2HPO_4$, in a complete nutrient solution, upon the correlative transpiration of the wheat seedlings. Since, however, the quantities of these salts used were not of the same equivalent weights, the specific actions of these compounds could not be compared with one another. In order to discover whether the different chemical salts of the same strength have different specific action upon the transpiration per gram of dry matter of the wheat seedlings, the following experiment was conducted in which a large number of salts were employed with equivalent weights. In order to find out also, whether the different ions influence the transpiration differently, the chemical salts were chosen in such a manner that when they were grouped in pairs they could have common cations or anions. It was assumed that the common cations, everything else being equal, would affect the transpiration about the same, and any apparent difference present could be logically attributed to the uncommon anions, and vice versa.

The salts that were used for these purposes were $NaNO_3$, $KNO_3$, $Na_2HPO_4$, $K_2HPO_4$, $MgSO_4$, $(NH_4)_2SO_4$, $MgCl_2$, $(NH_4)_2CO_3$, $CaCl_2$, $Ca(NO_3)_2$ and $K_2CO_3$.

The possible combinations that could be made from these salts, so that there would be common cations or anions, are as follows:

$$\left\{\begin{array}{l} NaNO_3 \\ KNO_3 \end{array}\right. \qquad \left\{\begin{array}{l} NaNO_3 \\ Na_2HPO_4 \end{array}\right. \qquad \left\{\begin{array}{l} KNO_3 \\ K_2HPO_4 \end{array}\right. \qquad \left\{\begin{array}{l} Na_2HPO_4 \\ K_2HPO_4 \end{array}\right.$$

$$\left\{\begin{array}{l} CaCl_2 \\ Ca(NO_3)_2 \end{array}\right. \qquad \left\{\begin{array}{l} CaCl_2 \\ MgCl_2 \end{array}\right. \qquad \left\{\begin{array}{l} Ca(NO_3)_2 \\ NaNO_3 \end{array}\right. \qquad \left\{\begin{array}{l} Ca(NO_3)_2 \\ KNO_3 \end{array}\right.$$

$$\left\{\begin{array}{l} K_2CO_3 \\ (NH_4)_2CO_3 \end{array}\right. \left\{\begin{array}{l} K_2CO_3 \\ KNO_3 \end{array}\right. \quad \left\{\begin{array}{l} K_2CO_3 \\ K_2HPO_4 \end{array}\right. \quad \left\{\begin{array}{l} MgSO_4 \\ MgCl_2 \end{array}\right.$$

$$\left\{\begin{array}{l} (NH_4)_2SO_4 \\ MgSO_4 \end{array}\right. \left\{\begin{array}{l} (NH_4)_2CO_3 \\ K_2CO_3 \end{array}\right. \left\{\begin{array}{l} (NH_4)_2CO_3 \\ (NH_4)_2SO_4 \end{array}\right. \left\{\begin{array}{l} \\ \end{array}\right.$$

The strength of all these salt solutions was $N/50$. In order that the plants might make a normal growth, 50 c.c. of a complete nutrient solution of a density of 4,500 p.p.m., were added in three liters of each one of these salt solutions. It was assumed here that the addition of this nutrient solution would not interfere with the object of the experiment, inasmuch as exactly the same quantity of it was added to each one of the salt solutions, and that it should have the same effect in all of them.

The following table shows the preparation of these salt solutions in detail.

TABLE XXXV.—*Preparation of the Different Chemical Salt Solutions.*

| Name of Salt. | Grams in 3 Liters. | No. c.c. of Complete Nutrient Solution Added. |
|---|---|---|
| $NaNO_3$ | 5.100 | 50 |
| $KNO_3$ | 6.066 | 50 |
| $Na_2HPO_4 \cdot 12H_2O$ | 7.158 | 50 |
| $K_2HPO_4$ | 3.480 | 50 |
| $MgSO_4 \cdot 7H_2O$ | 7.392 | 50 |
| $(NH_4)_2SO_4$ | 3.960 | 50 |
| $(NH_4)_2CO_3$ | 5.760 | 50 |
| $CaCl_2$ | 3.327 | 50 |
| $Ca(NO_3)_2$ | 4.920 | 50 |
| $MgCl_2 \cdot 6H_2O$ | 6.096 | 50 |
| $K_2CO_3$ | 4.146 | 50 |

The specific action of each one of these salt solutions was studied both in solution and sand cultures. Each salt solution contained 24 plants in the case of the former and 36 plants in the case of the latter.

Both cultures were conducted at the same time and were continued four weeks, the longest of any experiment. At the end of this period the following notes were taken in regard to the general growth and appearance of both the tops and roots.

In the sand cultures the plants in all the different salt solutions looked healthy and made a good growth. The size of the latter appeared to decrease in this order: $KNO_3$, $Ca(NO_3)_2$, $NaNO_3$ $(NH_4)_2CO_3$, $(NH_4)_2SO_4$, $K_2CO_3$, $MgSO_4$, $CaCl_2$, $MgCl_2$, $Na_2HPO_4$, $K_2HPO_4$.

Here it should be noted that the plants in the $(NH_4)_2CO_3$ solution refused to grow at the beginning, in fact they looked as though they were going to die, but by the end of the first week they began to recover and to grow quite rapidly and by the expiration of the experiment they ranked fourth in magnitude of growth among the plants from different salts.

In the solution cultures the tops appeared to be healthy and to have made a fair growth in all the different salt solutions except in the solution of $(NH_4)_2CO_3$ in which they looked very small, unhealthy, and were about to die. The amount of growth made by the plants in the various salt solutions decreased in this order: $Ca(NO_3)_2$, $NaNO_3$, $KNO_3$, $K_2CO_3$, $MgCl_2$, $MgSO_4$, $CaCl_2$, $Na_2HPO_4$, $K_2HPO_4$, $(NH_4)_2SO_4$, and $(NH_4)_2CO_3$. Apparently this order is not exactly the same as that in the sand cultures.

The growth and morphology of the roots in the solution cultures varied considerably among the different salt solutions. The roots in the solutions of $NaNO_3$, $KNO_3$, $Na_2HPO_4$, $K_2HPO_4$, $CaCl_2$, and $Ca(NO_3)_2$ looked healthy, turgid, and large. In the solutions of $MgSO_4$, $MgCl_2$, $(NH_4)_2SO_4$, $(NH_4)_2CO_3$, and $K_2CO_3$ they were very small, flaccid, and unhealthy. In the latter solutions they had hardly made any growth since they were placed there. Their tips were dark pale in color. The order of growth in all the different solutions seemed to decrease as follows: $K_2HPO_4$, $CaCl_2$, $Na_2HPO_4$, $Ca(NO_3)_2$, $NaNO_3$, $KNO_3$, $K_2CO_3$, $MgCl_2$, $MgSO_4$, $(NH_4)_2SO_4$, and $(NH_4)_2CO_3$.

The tops were harvested, dried, weighed, and the transpiration per gram of dry matter determined. These data are given herewith in Tables XXXVI and XXXVII.

TABLE XXXVI.—*Effect of Different Chemical Salts Upon the Transpiration Per Gram of Dry Matter of Wheat Seedlings Grown in Solution Cultures.*

| Name of Salt Solution. | Density of Salt Solution. | Grams of Dry Matter Produced. | Grams of Water Transpired. | Grams of Transpiration per Gram of Dry Matter. |
|---|---|---|---|---|
| $K_2HPO_4$........ | *n*/50 | .5879 | 257.2 | 437.5 |
| $Na_2HPO_4$....... | *n*/50 | .6067 | 250.6 | 413.1 |
| $CaCl_2$.......... | *n*/50 | .6440 | 264.1 | 410.1 |
| $NaNO_3$........ | *n*/50 | .9374 | 348.3 | 371.5 |
| $Ca(NO_3)_2$....... | *n*/50 | .9821 | 343.0 | 349.2 |
| $KNO_3$......... | *n*/50 | .9370 | 300.2 | 320.4 |
| $(NH_4)_2SO_4$...... | *n*/50 | .4780 | 110.2 | 230.6 |
| $K_2CO_3$ ........ | *n*/50 | .8000 | 159.2 | 199.0 |
| $MgCl_2$......... | *n*/50 | .7813 | 125.9 | 161.2 |
| $MgSO_4$......... | *n*/50 | .7530 | 108.6 | 144.2 |
| $(NH_4)_2CO_3$..... | *n*/50 | .4079 | 55.7 | 136.2 |
|  | *n*/50 |  |  |  |

TABLE XXXVII.—*Effect of Different Chemical Salts Upon the Transpiration Per Gram of Dry Matter of Wheat Seedlings Grown in Sand Cultures.*

| Name of Salt Solution. | Density of Salt Solution. | Grams of Dry Matter Produced. | Grams of Water Transpired. | Grams of Transpiration per Gram of Dry Matter. |
|---|---|---|---|---|
| $K_2HPO_4$ | n/50 | .6654 | 283.3 | 425.8 |
| $Na_2HPO_4$ | n/50 | .6784 | 288.5 | 425.3 |
| $NaNO_3$ | n/50 | 1.4650 | 598.5 | 408.5 |
| $K_2CO_3$ | n/50 | .7557 | 308.2 | 408.0 |
| $CaCl_2$ | n/50 | .7110 | 270.2 | 380.0 |
| $KNO_3$ | n/50 | 1.7910 | 677.4 | 378.5 |
| $MgCl_2$ | n/50 | .7008 | 231.1 | 329.8 |
| $Ca(NO_3)_2$ | n/50 | 1.5660 | 503.1 | 321.2 |
| $MgSO_4$ | n/50 | .7280 | 231.7 | 318.3 |
| $(NH_4)_2CO_3$ | n/50 | 1.1233 | 350.1 | 311.7 |
| $(NH_4)_2SO_4$ | n/50 | .9841 | 188.4 | 191.4 |

It appears from these tables that the amount of transpiration per gram of dry matter is markedly different among the various salts. It varies from 136.2 to 437.5 grams in the case of the solution cultures, and from 191.4 to 425.8 grams in the case of the sand cultures. It is greatest in those salts which are considered to be of plant food value, and smallest in those that are not of nutrient value; and likewise, it is larger in some of the salts with or without plant food value respectively. The salts in which it seems to be the greatest are $K_2HPO_4$, $Na_2HPO_4$, $CaCl_2$, $NaNO_3$, $KNO_3$, $Ca(NO_3)_2$ and $K_2CO_3$. Those in which it appears to be the smallest are $(NH_4)_2CO_3$, $(NH_4)_2SO_4$ and $MgCl_2$. It will be noticed that its magnitude is not affected by all the different salts in exactly the same order in both kinds of cultures—indicating that the specific action of some of the compounds does not manifest itself exactly the same in solution and sand cultures. For instance in the solution cultures it is inhibited in this order: $(NH_4)_2CO_3 > MgSO_4 > MgCl_2 > K_2CO_3 > (NH_4)_2SO_4 > KNO_3 > Ca(NO_3)_2 > NaNO_3 > CaCl_2 > Na_2HPO_4 > K_2HPO_4$; while in the sand cultures it is inhibited in the following order: $(NH_4)_2SO_4 > (NH_4)_2CO_3 > MgSO_4 > Ca(NO_3)_2 > MgCl_2 > KNO_3 > CaCl_2 > K_2CO_3 > NaNO_3 > Na_2HPO_4 > K_2HPO_4$. In both cultures it was the least inhibited by the $Na_2HPO_4$ and $K_2HPO_4$. This point is indeed very significant because it confirms the results of the previous experiment and also the observations of Reed.[34]

Mention has already been made that this experiment was designed to ascertain also whether the ions of the different salts would also exert any specific effect upon the transpiration of the wheat seedlings.

[34] Loc. cit.

This information could be obtained, as already stated, by comparing the results of salts having common cations and different anions and vice versa, and any significant difference present would be logically attributed to the uncommon cations or anions, assuming that common cations or anions would produce the same effect. The data secured upon this subject are very striking and are represented in Table XXXVIII.

TABLE XXXVIII.—*Effect of Ions Upon the Transpiration Per Gram of Dry Matter of Wheat Seedlings Grown in Solution and Sand Cultures.*

| Combination of Salts. | Grams of Transpiration per Gram of Dry Matter in Solution Cultures. | | Grams of Transpiration per Gram of Dry Matter in Sand Cultures. | |
|---|---|---|---|---|
| $NaNO_3$ | | 371.5 | | 408.5 |
| $KNO_3$ | | 320.4 | | 378.5 |
| Transpiration reduced by | K | 51.1 | K | 30.0 |
| $Na_2HPO_4$ | | 413.1 | | 425.3 |
| $K_2HPO_4$ | | 437.5 | | 425.8 |
| Transpiration reduced by | Na | 24.4 | Na | 0.5 |
| $Ca(NO_3)_2$ | | 349.2 | | 321.2 |
| $NaNO_3$ | | 371.5 | | 408.5 |
| Transpiration reduced by | Ca | 22.3 | Ca | 87.3 |
| $Ca(NO_3)_2$ | | 349.2 | | 321.2 |
| $KNO_3$ | | 320.4 | | 378.5 |
| Transpiration reduced by | K | 28.8 | Ca | 57.3 |
| $CaCl_2$ | | 410.1 | | 380.0 |
| $MgCl_2$ | | 161.2 | | 329.8 |
| Transpiration reduced by | Mg | 248.9 | Mg | 50.2 |
| $(NH_4)_2SO_4$ | | 230.6 | | 191.4 |
| $MgSO_4$ | | 144.2 | | 318.3 |
| Transpiration reduced by | Mg | 86.4 | $NH_4$ | 126.9 |
| $(NH_4)_2CO_3$ | | 136.2 | | 311.7 |
| $K_2CO_3$ | | 199.0 | | 408.0 |
| Transpiration reduced by | $NH_4$ | 63.8 | $NH_4$ | 93.3 |
| $NaNO_3$ | | 371.5 | | 408.5 |
| $Na_2HPO_4$ | | 413.1 | | 425.3 |
| Transpiration reduced by | $NO_3$ | 41.6 | $NO_3$ | 16.8 |
| $KNO_3$ | | 378.5 | | 320.4 |
| $K_2HPO_4$ | | 425.8 | | 437.5 |
| Transpiration reduced by | $NO_3$ | 47.3 | $NO_3$ | 117.1 |
| $CaCl_2$ | | 410.1 | | 380.0 |
| $Ca(NO_3)_2$ | | 349.2 | | 321.2 |
| Transpiration reduced by | $NO_3$ | 60.9 | $NO_3$ | 58.8 |
| $K_2CO_3$ | | 199.0 | | 408.0 |
| $KNO_3$ | | 320.4 | | 378.5 |
| Transpiration reduced by | $CO_3$ | 121.4 | $NO_3$ | 29.5 |
| $K_2CO_3$ | | 199.0 | | 408.0 |
| $K_2HPO_4$ | | 437.5 | | 425.8 |
| Transpiration reduced by | $CO_3$ | 238.5 | $CO_3$ | 17.8 |
| $MgSO_4$ | | 144.2 | | 318.3 |
| $MgCl_2$ | | 161.2 | | 329.8 |
| Transpiration reduced by | $SO_4$ | 17.0 | $SO_4$ | 11.5 |
| $(NH_4)_2CO_3$ | | 136.2 | | 311.7 |
| $(NH_4)_2SO_4$ | | 230.6 | | 191.4 |
| Transpiration reduced by | $CO_3$ | 94.4 | $SO_4$ | 120.3 |

It is evident that with the exception of four combinations out of fourteen, both cultures agree remarkably well, and show that the specific effect of the different ions upon the transpiration per gram of dry matter of the wheat seedlings, is significantly different, ranging from 0.5 to 248.9 grams in the case of the cations, and from 11.5 to 238.5 grams in the case of the anions. Starting first with the cations, K had a greater reducing effect upon the transpiration than Na, when they are both combined with $NO_3$, but when they are in the form of $K_2HPO_4$ and $Na_2HPO_4$ respectively, it is Na that has the larger diminishing effect indicating that the specific action of these cations in affecting transpiration probably depends upon the kind of anions to which they are attached. The Ca united also to the $NO_3$ anion reduced the transpiration more than the Na in both cultures, and more than the K in the sand cultures, but not so in the solution culture. In the latter it was K that had the greater diminishing effect, indicating that the same cation may not affect the transpiration the same in both the sand and solution cultures, an inference which seems to be borne out by three other cases which will be mentioned shortly. When Ca is compared with Mg the latter is the greater water conserver of the two. When Mg is in turn compared with the $NH_4$, the $NH_4$ causes the plants to transpire less water than the former. This, however, is not true in both cultures, for in the solution cultures it is the Mg that produced the greater diminution in the water vapor rather than the $NH_4$. The $NH_4$, however, is superior to K as a water conserver.

In the case of the anions the $NO_3$ reduces the transpiration per gram of dry matter more than the $PO_4$, Cl, and more than the $CO_3$ in the sand culture but less in the solution culture; $CO_3$ more than the $PO_4$; $SO_4$ more than Cl, and more than $CO_3$ in the sand culture but less in the solution culture.

It seems then that the different cations and anions play their own independent part in affecting the transpiration of the wheat seedlings. How they are able to do this cannot be said with certainty at this time. It might be suggested, however, that the probable explanation lies in their physical properties, and in their different physiological or chemical effects. As to the first, it is well known that the different cations and anions cause different osmotic pressure, lowering of the vapor pressure, and the like, all of which, together with the stimulative physiological or chemical action that some of them appear to possess, probably cause them to bring about such marked differences in the relative transpiration.

These results seem to throw further light upon the validity of the hypothesis of osmotic pressure and stimulation as already suggested, in the early part of this paper, to account for the phenomena brought about by the various densities of solutions. If the different ions have an independent specific action upon the transpiration, and this specific action is probably due to their different physiological effects and to the different degrees of their physical properties, then when these various ions are brought together, as was done in the case of the complete nutrient solution, they will affect the transpiration probably by the sum total of their specific actions. If the number of these ions is diminished by reducing the density of the solution, then the magnitude or intensity of their physical properties is also reduced, and consequently, the correlative transpiration is increased. If the number of the ions still continues to decrease a point is finally reached where the maximum relative transpiration takes place, due to the decreased power of the physical properties of the ions to withhold the water, and to the maximum predominant power of some or all of the ions to stimulate transpiration. From this point down the relative transpiration decreases because the stimulative action of the ions also diminishes.

Just as in most of the preceding experiments, so also in the present one, the transpiration per gram of dry weight appears to be greater in the sand than in the solution culture, as will be seen in Table XXXIX.

Table XXXIX.—*Difference in the Amount of Transpiration Per Gram of Dry Matter Between Solution and Sand Cultures.*

| Name of Salt. | Grams of Transpiration per Gram of Dry Matter in Solution Cultures. | Grams of Transpiration per Gram of Dry Matter in Sand Cultures. | Greater Transpiration per Gram of Dry Matter in Sand Over Solution Cultures. |
|---|---|---|---|
| $NaNO_3$...... | 371.5 | 408.5 | 37.0 |
| $KNO_3$....... | 320.4 | 378.5 | 58.1 |
| $Na_2HPO_4$.... | 413.1 | 425.3 | 12.2 |
| $K_2HPO_4$..... | 437.5 | 425.8 | −11.7 |
| $MgSO_4$...... | 144.2 | 318.3 | 174.1 |
| $(NH_4)_2SO_4$... | 230.6 | 191.4 | −39.2 |
| $MgCl_2$...... | 161.2 | 329.8 | 168.6 |
| $(NH_4)_2CO_3$... | 136.2 | 311.7 | 175.5 |
| $CaCl_2$....... | 410.1 | 380.0 | −30.1 |
| $Ca(NO_3)_2$.... | 349.2 | 321.2 | −28.0 |
| $K_2CO_3$...... | 199.0 | 408.0 | 209.0 |

With the exception of four cases, as indicated by the minus sign, these figures show that the amount of water transpired to produce one gram of dry matter is greater in the sand than in the solution cultures having the same densities of solution.

In regard to the actual dry matter between the solution and sand cultures, it does not appear to run in the same order as in most of the foregoing experiments, namely, to be larger in the solution than in the sand cultures. These data are given herewith in Table XL.

TABLE XL.—*Difference in the Actual Dry Matter Between the Solution and Sand Cultures.*

| Name of Salt. | Average Weight per Single Plant in Solution Cultures. | Average Weight per Single Plant in Sand Cultures. | Greater Weight of Dry Matter in Solution Cultures. |
|---|---|---|---|
| $NaNO_3$ . . . . . | .03907 | .04070 | —.00163 |
| $KNO_3$ . . . . . | .03905 | .04995 | —.01070 |
| $Na_2HPO_4$ . . . | .02528 | .01884 | .00644 |
| $K_2HPO_4$ . . . . | .02450 | .01848 | .00602 |
| $MgSO_4$ . . . . . . | .03137 | .02023 | .01114 |
| $(NH_4)_2SO_4$ . . . | .01992 | .02733 | —.00741 |
| $MgCl_2$ . . . . . . | .03256 | .01947 | .01309 |
| $(NH_4)_2CO_3$ . . | .01700 | .03120 | —.01420 |
| $CaCl_2$ . . . . . . . | .02684 | .01975 | .00709 |
| $Ca(NO_3)_2$ . . . . | .04093 | .04350 | —.00257 |
| $K_2CO_3$ . . . . . . | .03334 | .02097 | .01237 |

It will be seen that in six out of eleven cases the actual dry matter is greater in the solution cultures, and in the other five cases it is larger in the sand cultures. Hence, the differences are not sufficiently marked to warrant any conclusion one way or the other.

## *Transpiration of Wheat Seedlings as Affected by Different Densities of Solution in Different Sized Particles of Sand and Soil.*

It was stated at the beginning of the investigation that the principal object of employing sand and soil of different textures, was to ascertain whether the size of particles would influence in any way the different densities of solution in affecting the transpiration of the wheat seedlings. This subject was suggested by the fact that the concentration of a solution is not the same when placed in different sized particles. It was realized at the outset, that this was a rather difficult point to determine on account of the many factors involved, due to the unequal area of the different sized particles, and therefore, to the different water holding capacities. If, for example, an equal quantity of solution was added to the different sized particles, the amount of physiological or available water would be different among them, and therefore, the plants would not be able to absorb it with an equal facility in all of them. On the other hand, if the various textures were brought up to the saturation point so as to eliminate the above factor there would be an inequality in the concentration due to the fact that different amounts of solution would be added, and the coarser particles which would take up the smaller quantity would have a much more dilute solution after the plants have grown for a while, than the finer particles which possess the greater water holding capacity and, therefore, would absorb the larger quantity of the solution. In order to compromise in a way with these factors three different moisture contents were employed, namely, (1) the same percentage of moisture was added to all the different sized particles; (2) different percentages but below the saturation point; and (3) brought up to the saturation point.

TABLE XLI.—*Difference in the Transpiration Per Gram of Dry Matter of Wheat Seedlings Between Clay Loam and Sandy Loam at 30 Percent and 25 Percent Moisture Content Respectively. Averages of Two Experiments.*

| Density of Solution in p.p.m. | Grams of Transpiration per Gram of Dry Matter in Clay Loam. | Grams of Transpiration per Gram of Dry Matter in Sandy Loam. | Greater Relative Transpiration in Clay Loam. |
|---|---|---|---|
| 4,500 | 522.5 | 479.7 | 42.8 |
| 2,250 | 617.5 | 551.0 | 66.5 |
| 750 | 617.1 | 523.8 | 93.3 |
| 375 | 665.0 | 503.0 | 162.0 |
| 187.5 | 712.4 | 523.6 | 188.8 |
| 93.5 | 753.1 | 537.7 | 215.4 |
| 0.0 | 659.6 | 518.3 | 141.3 |
| Average | | | 130 |

TABLE XLII.—*Difference in the Transpiration Per Gram of Dry Matter of Wheat Seedlings Between Finer and Coarser Particles of Sand at 30 Percent Moisture Content. Averages of Two Experiments.*

| Density of Solution in p.p.m. | Grams of Transpiration per Gram of Dry Matter in Sand No. 1. | Grams of Transpiration per Gram of Dry Matter in Sand No. 2. | Greater Relative Transpiration in Sand No. 2. |
|---|---|---|---|
| 4,500 | 393.7 | 449.6 | 55.9 |
| 2,250 | 417.3 | 434.2 | 16.9 |
| 750.50 | 426.2 | 435.2 | 9.0 |
| 375 | 482.3 | 471.4 | −10.9 |
| 187.5 | 394.9 | 443.8 | 48.9 |
| 93.5 | 389.7 | 409.1 | 19.4 |
| 0.0 | 432.7 | 382.4 | −50.3 |
| Average | | | 12.7 |

The sizes of particles of sand used for this work were numbers 1 and 2, having a diameter of 1 and 2 millimeters respectively. The soil consisted of the Dunkirk clay loam and of the Dunkirk sandy loam, the former being assumed to contain the finer and the latter the coarser particles. According to the three different moisture contents above, in the first both sizes of sand contained 30 percent; in the second the finer particles of both the sand and the soil contained

30 per cent, and the coarser particles, 25 percent; in the third the smaller size of sand contained 37 percent as against 33.5 percent in the larger. The results obtained on both sized particles, at all three different moisture contents, are represented herewith in Tables XLI–XLIV.

Table XLIII.—*Difference in the Transpiration Per Gram of Dry Matter of Wheat Seedlings Between Finer and Coarser Particles of Sand at 30 Percent and 25 Percent Moisture Content Respectively. Averages of Two Experiments.*

| Density of Solution in p.p.m. | Grams of Transpiration per Gram of Dry Matter in Sand No. 1. | Grams of Transpiration per Gram of Dry Matter in Sand No. 2. | Greater Relative Transpiration in Sand No. 2. |
|---|---|---|---|
| 4,500 | 385.7 | 426.1 | 40.4 |
| 2,250 | 422.9 | 480.0 | 57.1 |
| 750 | 471.9 | 487.3 | 15.4 |
| 375 | 453.4 | 501.3 | 47.9 |
| 187.5 | 450.1 | 510.3 | 60.2 |
| 93.5 | 456.1 | 512.0 | 55.9 |
| 0.0 | 422.3 | 419.7 | − 2.6 |
| Average | | | 39.2 |

Table XLIV.—*Difference in the Transpiration Per Gram of Dry Matter of Wheat Seedlings Between Finer and Coarser Particles of Sand at Saturation Point. Averages of Two Experiments.*

| Density of Solution in p.p.m. | Grams of Transpiration per Gram of Dry Matter in Sand No. 1. | Grams of Transpiration per Gram of Dry Matter in Sand No. 2. | Greater Relative Transpiration in Sand No. 2. |
|---|---|---|---|
| 4,500 | 348.2 | 396.9 | 48.7 |
| 2,250 | 458.9 | 424.1 | 15.2 |
| 750 | 462.2 | 460.0 | − 2.2 |
| 375 | 467.2 | 468.9 | 1.7 |
| 187.5 | 502.8 | 490.9 | −11.9 |
| 93.5 | 454.1 | 508.0 | 54.0 |
| 0.0 | 484.5 | 538.5 | 54.0 |
| Average | | | 22.8 |

The preceding tables show that in the case of the soil, the clay loam, which is supposed to possess the finer particles, gave off more transpiration per gram of dry matter than the sandy loam, with the coarser particles; the average difference being 130 grams greater in the former than in the latter. In the case of the sand, the finer size diminished the relative transpiration in all three moisture contents, more than the coarser one; the average differences being 12.7 grams in the same amount of moisture content; 39.2 grams in the different amounts but below the saturation point; and 22.8 grams at the saturation point, less in the finer size than in the coarser one.

It is thus seen, that the fine-textured soil caused more relative transpiration than the coarse one, while the reverse was true in the case of the sand. Just why there should be this disagreement cannot be explained with absolute certainty.

Leaving out of consideration the soil, because this presents two many complex and uncontrollable factors, it is indeed apparent that the fine particles of the sand do tend to cause less transpiration per gram of dry matter than the coarser particles. Whether this is entirely due to the physiological water and to the inequality of the concentrations, or also to the different density of the solution due to different absorptive power of the two different sizes of sand, cannot be asserted with positiveness.

Table XLV.—*Difference in Plant Growth Between Fine and Coarse Textured Soil at 30 Percent and 25 Percent Moisture Content Respectively. Averages of Two Experiments.*

| Density of Solution in p.p.m. | Grams of Dry Matter in Clay Loam. | Grams of Dry Matter in Sandy Loam. | Greater Growth in Clay Loam. |
|---|---|---|---|
| 4,500 | .8778 | .7377 | .1401 |
| 2,250 | .6805 | .5449 | .1356 |
| 750 | .4557 | .4031 | .0526 |
| 375 | .4005 | .3672 | .0333 |
| 187.5 | .3773 | .3664 | .0109 |
| 93.5 | .3477 | .3941 | —.0464 |
| 0.0 | .3269 | .3516 | —.0247 |
| Average | | | .0430 |

Table XLVI.—*Difference in Plant Growth Between Fine and Coarse Size of Sand at 30 Percent and 25 Percent Moisture Content Respectively. Averages of Two Experiments.*

| Density of Solution in p.p.m. | Grams of Dry Matter in Sand No. 1. | Grams of Dry Matter in Sand No. 2. | Greater Growth in Sand No. 1. |
|---|---|---|---|
| 4,500 | .8095 | .7953 | .0142 |
| 2,250 | .7624 | .7209 | .0415 |
| 750 | .5604 | .5438 | .0166 |
| 375 | .4573 | .4741 | —.0168 |
| 187.5 | .4029 | .3602 | .0427 |
| 93.5 | .3598 | .3413 | .0185 |
| 0.0 | .3257 | .3149 | .0108 |
| Average | | | .0182 |

In connection with the influence of the different sized particles upon the correlative transpiration, it will be interesting to note also their effect upon the plant growth. It is claimed that, everything else being equal, the plants will make a greater growth in the presence of finer particles than in the coarser ones. This is attributed to the fact that the root hairs come in more intimate contact and in greater area, in the former than in the latter; and since the density of solution is greater around each particle, due to absorption or condensation, than further distant, the root hairs come in contact with more plant food in the finer particles than in the coarser, and, consequently, the plants can make a greater growth in the former than in the latter. The results obtained upon this subject with the two sizes of particles at the three different moisture contents as used above, are shown in Tables XLV to XLVIII, inclusive.

TABLE XLVII.—*Difference in Plant Growth Between Fine and Coarse Size of Sand at Saturation Point. Averages of Two Experiments.*

| Density of Solution in p.p.m. | Grams of Dry Matter in Sand No. 1. | Grams of Dry Matter in Sand No. 2. | Greater Growth in Sand No. 1. |
|---|---|---|---|
| 4,500 | .2336 | .2577 | —.0241 |
| 2,250 | .2500 | .2321 | .0179 |
| 750 | .2498 | .2667 | —.0169 |
| 375 | .2674 | .2751 | —.0077 |
| 187.5 | .2735 | .2590 | .0145 |
| 93.5 | .2791 | .2512 | .0279 |
| 0.0 | .2428 | .2223 | .0205 |
| Average | | | .0046 |

TABLE XLVIII.—*Difference in Plant Growth Between Fine and Coarse Size of Sand at 30 Percent Moisture Content. Averages of Two Experiments.*

| Density of Solution in p.p.m. | Grams of Dry Matter in Sand No. 1. | Grams of Dry Matter in Sand No. 2. | Greater Growth in Sand No. 2. |
|---|---|---|---|
| 4,500 | 1.0424 | 1.4607 | .4183 |
| 2,250 | .7773 | .9081 | .1308 |
| 750 | .7592 | .6477 | —.1115 |
| 375 | .5132 | .5180 | .0048 |
| 187.5 | .5154 | .4875 | —.0279 |
| 93.5 | .4776 | .4320 | —.0456 |
| 0.0 | .4119 | .4321 | .0202 |
| Average | | | .0556 |

The foregoing tables indicate that in the case of the same percentage of moisture content, the coarser size of sand produced more dry matter than the sand of the finer particles, while in all the other different percentages of moisture content, both with the sand and soil, the reverse was true, the finer particles produced more growth than the coarser ones.

## SUMMARY.

In the foregoing investigation an attempt was made to study the effect of different densities of solutions and of various chemical compounds upon the relative transpiration of plants. The results obtained may be summarized as follows:

The transpiration per gram of dry matter of wheat seedlings grown in solution, sand, and soil cultures containing 4,500, 2,250, 750, 375, 187.5, 93.5 and 0.0 p.p.m. respectively of a complete nutrient solution, increased in every case with the decrease in density down to a certain point and then decreased with the further diminution in concentration; while the actual dry matter produced increased with the rise in density.

This general run of the relative transpiration was explained thus: The increase from the highest concentration to that where the change occurs, was thought might be due to the decreased osmotic pressure of the solution and to the decreased density of the cell sap; while the decrease from where the change occurs to the lowest density, was believed might be due to the decreased stimulative action of the dilute solutions.

The relation of the density of the solution to that of the cell sap was tested experimentally and it was found that the density of the latter increased with the concentration of the former.

The relative transpiration of corn and bean seedlings grown in solution, and in sand cultures containing the same solutions as above, also tended to increase with the reduction in density down to a certain dilution and then diminish with the further decline in concentration; while the plant growth tended to increase with the concentration.

Both the corn and bean seedlings transpired less water per gram of dry matter than the wheat seedlings, and the beans less than the corn.

The correlative transpiration of wheat seedlings grown in solution and in sand cultures treated with the same number and strength of densities as above, of NaCl and $Na_2SO_4$, with each density containing exactly the same amount of a complete nutrient solution, increased in the solution cultures of both non-nutrient salts from the highest density to that of the lowest; in the sand cultures of the same salt solutions it tended to increase with the decrease in density down to a certain point and then to diminish with the further reduction in concentration. The plant growth in this case was greatest in the intermediate densities.

The relative transpiration of wheat seedlings grown in different densities of agar containing the same amount of a nutrient solution increased with the decrease in density.

By increasing the amount of $Ca(NO_3)_2$, KCl and $Na_2HPO_4$ in a complete nutrient solution, the relative transpiration of the wheat seedlings grown in solution cultures and sand cultures containing these solutions, decreased in the case of the $Ca(NO_3)_2$ with the increase in density; but increased in the case of the $Na_2HPO_4$, while in the case of the KCl it diminished in the sand cultures but increased in the solution cultures.

Fiftieth normal solutions of $NaNO_3$, $KNO_3$, $Na_2HPO_4$, $K_2HPO_4$, $Ca(NO_3)_2$, $CaCl_2$, $KCO_3$, $(NH_4)_2CO_3$, $(NH_4)_2SO_4$, $MgSO_4$, and $MgCl_2$, to each one of which was added exactly the same amount of a complete nutrient solution, affected the relative transpiration of the wheat seedlings grown in solution and sand cultures very differently, and the order of magnitude of this effect was not exactly the same in both kinds of cultures for all the salts. In the solution culture the relative transpiration was inhibited in this order: $(NH_4)_2CO_3 > MgSO_4 > MgCl_2 > K_2CO_3 > (NH_4)_2SO_4 > KNO_3 > Ca(NO_3)_2 > NaNO_3 > CaCl_2 > Na_2HPO_4 > K_2HPO_4$; while in the sand culture it was reduced thus: $(NH_4)_2SO_4 > (NH_4)_2CO_3 > MgSO_4 > Ca(NO_3)_2 > MgCl_2 > KNO_3 > CaCl_2 > K_2CO_3 > NaNO_3 > Na_2HPO_4 > K_2HPO_4$. In both cases the non-nutrient salts diminished it more than the plant food salts.

The ions of the above salts also showed a significantly different specific action upon the relative transpiration. In the case of the cations the K had a greater reducing effect than the Na when they were both combined with the $NO_3$, but when they were united with the $PO_4$, it was the Na that had the greater diminishing action; the Ca attached also to the $NO_3$ was a better water conserver than the Na in both kinds of cultures and superior to the K in the sand cultures but inferior in the solution culture. Mg, on the other hand, was more effective than the Ca, and $NH_4$ more than the Mg, in the sand culture but not so in the solution culture; $NH_4$ was also more effective than the K. In the case of the anions the $NO_3$ reduced the relative transpiration more than the $PO_4$ and Cl, and more than the $CO_3$ in the sand culture but less in the solution culture; $CO_3$ more than the $PO_4$; $SO_4$ more than the Cl, and more than the $CO_3$ in the sand culture but less in the solution culture.

Coarse textured soil diminished the correlative transpiration more than the fine textured one, while the finer size of sand reduced it more than the coarser size.

The amount of transpiration per gram of dry matter tended to be larger in the sand than in the solution culture receiving the same densities of solution, while the actual dry matter produced tended to be greater in the latter than in the former.

It is thus seen that the transpiration of wheat seedlings is affected by different densities of nutrient and non-nutrient solutions, by different chemical salts and by the ions of these salts and by different sized particles of sand and soil.

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# THE EFFECT OF SOIL MOISTURE AND TEMPERATURE ON THE AVAILABILITY OF PLANT NUTRIENTS IN THE SOIL.*

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## HISTORICAL.

In 1899, Von Seelhorst[1] showed that fertilizers and the moisture content of the soil influenced the form and composition of the barley plant. He noticed that the maximum root development always occurred in the soil containing a medium or low moisture content and was quite limited in the high moisture soil. The application of nitrogenous fertilizers increased the root development while mineral fertilizers decreased it. The tendency of the plants to stool was much greater where the moisture content of the soil was high, especially following the application of a nitrogenous fertilizer. Where there was an abundance of soluble nitrogen in the soil an increase in the soil moisture content also increased the strength of the culms but without nitrogen this same increase in soil moisture decreased the strength of the barley culms. The length of spikes was affected in the same way. Potassium, either alone or in combination with phosphorus and nitrogen, increased the strength of culms. Where the moisture content of the soil was high the percentage of grain to straw was decreased. This decrease was greatest where no nitrogen was applied. Von Seelhorst also found that nitrogenous fertilizers increased the percentage of nitrogen in the plants. The moisture content of the soil affected the nitrogen content of the crop to a very limited extent where only mineral fertilizers were added, while there was a noticeable decrease in the percentage nitrogen in the nitrogen-fertilized series following an increase in soil moisture.

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[1] Jour. fur Landw., Vol. 48 (1900), p. 325.

In 1902, Von Seelhorst,[2] as a result of experiments conducted with different varieties of wheat, oats and barley, concluded that the oat plant requires a much larger amount of moisture in the soil for its favorable growth than either wheat or barley. Oats produced the maximum proportion of grain to straw when grown in the high moisture soil whereas the wheat and barley produced the greatest proportion of grain to straw when grown in soil of medium moisture content. It was also shown that the variation in the percentage of nitrogen, as regards the different varieties tested, was not nearly so great as the variation induced within the same variety by changing the moisture content of the soil upon which it was grown. In every case the percentage of nitrogen in the crop decreased following an increase in soil moisture. There is also a close relation between the yield of crop and the percent nitrogen in the crop; the low yields being associated with a high nitrogen content and the high yields with a low nitrogen content.

As regards the effect of the moisture content of the soil upon the development of the above-ground portions of the plants, Von Seelhorst found that not only were the different species affected differently, but that different varieties within the same species showed marked variations as regards the character of growth produced under the different conditions.

As a result of a series of irrigation experiments conducted by

[2] Jour. fur Landw. (1903), p. 253.

Widtsoe,[3] in 1901 for the purpose of determining the effect of different quantities of water upon the chemical composition of wheat, peas, corn and sugar beets, the following conclusions were drawn:

"The variation in the ash of the entire wheat plant is not regular, though in the majority of cases the percentage of ash increases with the amount of water applied.

"The percentage of protein differs very little; in three out of five cuttings the percentage of protein is highest in the plants from the well watered plats.

"The percentage of the crude fiber is larger, in nearly every case, in the plants from the plats that received least water."

With regard to the whole pea plant the following conclusions are drawn:

"The percentage of ash in the whole pea plant varies in the opposite direction from that in the wheat plant. The plats that received most water carried plants that contained the smallest percentage of ash.

"The relative amount of protein increases in general as the amount of water applied diminishes.

"The percentage of nitrogen-free extract becomes larger as irrigation increases."

It was found that the moisture content of the soil affected the composition of the seeds more than any other parts of the plant.

"The percentage of protein in corn kernels was increased from 12.05 to 15.08 as the amount of irrigation decreased; in oat kernels from 14.07 to 20.79; in wheat kernels from 15.26 to 26.72. In all these seeds the fat and nitrogen-free extracts were increased by liberal waterings.

"Increased irrigation increased the starch content and decreased the protein content of potatoes.

"The composition of sugar beets seemed to be less strongly affected by irrigation than were other crops. Between twenty and twenty-five inches of water yielded beets with the highest sugar content."

In 1904, Von Seelhorst,[4] working with three varieties of oats, showed that as the moisture content of the soil increases, the nitrogen content of the straw decreases. Also, that albuminoid nitrogen decreases less rapidly than does the total nitrogen, hence we get an increase in the percentage of albuminoid nitrogen in total nitrogen following an increase in soil moisture. With the increase in moisture, the digestible albuminoid nitrogen decreases more rapidly than does the total albuminoid nitrogen.

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[3] Bull. 80, Utah Exper. Sta.

[4] Jour. fur Landw. (1905), p. 132.

As a result of this work Von Seelhorst concludes that there is a larger amount of digestible protein in straw grown during a dry year than in straw grown during a wet year.

In 1897, J. Wilms and Von Seelhorst[5] showed that the moisture content of the soil does not affect the ash constituents of the oat plant in the same way that it does the nitrogen content. Their results show a decrease in the nitrogen content of the plant following an increase in soil moisture, while the ash constituents increased following the same change in soil moisture. This was more noticeable in the case of potash than phosphoric acid. Also where potash was deficient in the soil it was also deficient in the plants growing on that soil, while the highest percentage of phosphoric acid was found in plants growing upon a soil deficient in soluble phosphoric acid.

## EXPERIMENTAL. PART I.

During the past five years (1903 to 1908) the Agricultural Experiment Station at Cornell University has been conducting, upon the college farm, a series of fertilizer tests with oats, timothy and corn. The soil upon which these tests have been made is described, by the Bureau of Soils at Washington, D. C., as "the silty phase of the Dunkirk Clay loam." It is quite tenacious and difficult to work except when the moisture conditions are most favorable. In all of the tests thus far made, the element which has proved to be most effective in producing an increased yield of crops, when applied under field conditions, is nitrogen.

In the winter of 1906–07 the writer conducted an experiment in the college greenhouse to determine the fertilizer requirements of this same soil, oats being used as an indicator. The results of this test, though quite consistent, differed markedly from those obtained under field conditions. The same combinations and amounts of fertilizers were used in both field and greenhouse tests. In the greenhouse phosphorus gave decidedly better results than either nitrogen or potassium, though nitrogen was quite effective in producing increased yields. Why this soil should not respond to fertilizer treatments made in the greenhouse in a similar manner as it did to the same treatments when given under field conditions, could not be explained. However, it was known that the soil in the greenhouse contained a higher content of moisture throughout the experi-

[5] Jour. fur Landw. (1898), p. 413.

ment than the average moisture content of the field soil for the growing season. Knowing that seasonal differences very often influence decidedly the action of fertilizers, and that these differences are due primarily to a varied rainfall and consequently a varied soil moisture content, it was decided to make a special study of the effect of soil moisture upon the action of fertilizers, and also the relation which the moisture content of the soil, together with fertilizers, bears to the general development and chemical constitution of the plant. The effect of the soil moisture upon the temperature of the soil was also observed and recorded.

### *Plan of Experiment.*

The work which is described in the following pages was begun in the fall of 1907. The soil was taken from one of the check plats (No. 729) belonging to the timothy fertilizer experiment. This plat has received no fertilization for many years past and consequently there was little danger of the results being influenced by any fertilizer residue which otherwise might have been present. The chemical composition[6] of this soil, as determined by the agricultural experiment station of the college shows no marked difference from that of normal soils. The percentage content of this soil, as regards the most important constituents, may be seen from the following table:

TABLE I.—*Chemical Analysis of Unfertilized Dunkirk Clay Loam.*

| Description. | Wt. of Sample. Grms. | Detritus. | Moisture. Percent. | N Percent. | $P_2O_5$ Percent. | CaO Percent. | MgO Percent. |
|---|---|---|---|---|---|---|---|
| 1st ft..... | 516.0 | 3.76 | 1.54 | .12 | .15 | .54 | .56 |
| 2d ft..... | 565.7 | 10.13 | 1.54 | .06 | .16 | .22 | .68 |
| 3d ft..... | 564.4 | 16.45 | 1.60 | .06 | .14 | .32 | .90 |
| 4th ft..... | 574.3 | 18.00 | 1.89 | .06 | .16 | .33 | .88 |
| | $K_2O$ Percent. | $Fe_2O_3$ Percent. | $Al_2O_3$ Percent. | | | | |
| 1st ft..... | .183 | 2.66 | 3.64 | | | | |
| 2d ft..... | .319 | 3.25 | 5.16 | | | | |
| 3d ft..... | .387 | 3.99 | 5.20 | | | | |
| 4th ft..... | .313 | 3.72 | 5.01 | | | | |

The pots used in this test were the ordinary 3-gallon earthen pots, there being 110 of these including the 26 pots containing the soil used in the fertilizer test of 1906–7. Each pot contained 7.35 kilograms of water-free soil, together with a small amount of gravel placed in the bottom to facilitate drainage. The 110 pots were divided into four series as follows:

[6] Hydrochloric acid digestion, 1.115 sp. gr.

Series 1: pots 1–26, containing the same soil which was used in the fertilizer test of 1906–7. The moisture content of this soil was maintained at 33.3 percent, this being the same amount of water kept in the soil during the first test.

Series 2: pots 27–54, having a soil moisture content of 17.6 percent.

Series 3: pots 55–82, having a soil moisture content of 29.0 percent.

Series 4: pots 83–110, having a soil moisture content of 42.8 percent.[7]

All moisture contents were calculated on the basis of water-free soil.

Rain water was used throughout the entire test. All treatments were run in duplicate and the scheme of fertilization was the same for each series.

In addition to the four series of pots just described, there were also three series of small wire baskets in which the soil treatment (moisture content and fertilization) as carried out in pot series 2, 3, and 4 was duplicated. The moisture content and fertilizer treatment of the soil in these baskets were the same as for the corresponding pot series. This method will be described later.

## POT TEST.

On November 18, one month after the soil was brought in from the field, it was thoroughly mixed and put in the pots. At this time a sample of soil was taken for moisture determination. On November 27, fertilizers were added at the following rates per acre:

*Series 1.*—Moisture content 33.3 percent.

Pots 1 and 2, no treatment.
Pots 3 and 4, 320 lbs. acid phosphate.
Pots 5 and 6, 80 lbs. muriate of potash.
Pots 7 and 8, 160 lbs. nitrate of soda.
Pots 9 and 10, 320 lbs. acid phos., 160 lbs. nitrate soda.
Pots 11 and 12, 320 lbs. acid phos., 80 lbs. muriate potash.
Pots 13 and 14, 160 lbs. nitrate soda, 80 lbs. muriate potash.
Pots 15 and 16, 320 lbs. acid phos., 80 lbs. mur. pot., 160 lbs. nit. soda.
Pots 17 and 18, 640 lbs. acid phos., 80 lbs. mur. pot., 160 lbs. nit. soda.
Pots 19 and 20, 640 lbs. acid phos., 80 lbs. mur. pot., 320 lbs. nit. soda.
Pots 21 and 22, 320 lbs. acid phos., 80 lbs. mur. pot., 320 lbs. nit. soda.
Pots 23 and 24, 10 tons stable manure.
Pots 25 and 26, 20 tons stable manure.

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[7] In series 2, 3, and 4 it was intended that the soil moisture contents should be maintained at 15, 22.5 and 30 percent respectively, but it was afterwards found that the calculations were made on the basis of wet soil. When calculated to water-free soil the actual percentages were 17.6, 29.0 and 42.8 respectively.

*Series 2.*—Moisture content 17.6 percent.

Pots 27 and 28, no treatment.
Pots 29 and 30, 320 lbs. acid phosphate.
Pots 31 and 32, 80 lbs. muriate potash.
Pots 33 and 34, 160 lbs. nitrate soda.
Pots 35 and 36, 320 lbs. acid phos., 160 lbs. nitrate soda.
Pots 37 and 38, 320 lbs. acid phos., 80 lbs. mur. pot.
Pots 39 and 40, 160 lbs. nitrate soda, 80 lbs. mur. pot.
Pots 41 and 42, 320 lbs. acid phos., 80 lbs. mur. pot., 160 lbs. nit. soda.
Pots 43 and 44, 640 lbs. acid phos., 80 lbs. mur. pot., 160 lbs. nit. soda.
Pots 45 and 46, 640 lbs. acid phos., 80 lbs. mur. pot., 320 lbs. nit. soda.
Pots 47 and 48, 320 lbs. acid phos., 80 lbs. mur. pot., 320 lbs. nit. soda.
Pots 49 and 50, 320 lbs. acid phos., 80 lbs. mur. pot., 640 lbs. nit. soda.
Pots 51 and 52, 10 tons stable manure.
Pots 53 and 54, 20 tons stable manure.

*Series 3.*—Moisture content 29.0 percent.

Pots 55 and 56, no treatment.
Pots 57 and 58, 320 lbs. acid phos.
Pots 59 and 60, 80 lbs. muriate of potash.
Pots 61 and 62, 160 lbs. nitrate of soda.
Pots 63 and 64, 320 lbs. acid phos., 160 lbs. nitrate soda.
Pots 65 and 66, 320 lbs. acid phos., 80 lbs. mur. pot.
Pots 67 and 68, 160 lbs. nitrate soda, 80 lbs. mur. pot.
Pots 69 and 70, 320 lbs. acid phos., 80 lbs. mur. pot., 160 lbs. nit. soda.
Pots 71 and 72, 640 lbs. acid phos., 80 lbs. mur. pot., 160 lbs. nit. soda.
Pots 73 and 74, 640 lbs. acid phos., 80 lbs. mur. pot., 320 lbs. nit. soda.
Pots 75 and 76, 320 lbs. acid phos., 80 lbs. mur. pot., 320 lbs. nit. soda.
Pots 77 and 78, 320 lbs. acid phos., 80 lbs. mur. pot., 640 lbs. nit. soda.
Pots 79 and 80, 10 tons stable manure.
Pots 81 and 82, 20 tons stable manure.

*Series 4.*—Moisture content 42.8 percent.

Pots 83 and 84, no treatment.
Pots 85 and 86, 320 lbs. acid phos.
Pots 87 and 88, 80 lbs. mur. of potash.
Pots 89 and 90, 160 lbs. nitrate of soda.
Pots 91 and 92, 320 lbs. acid phos., 160 lbs. nitrate of soda.
Pots 93 and 94, 320 lbs. acid phos., 80 lbs. mur. pot.
Pots 95 and 96, 160 lbs. nitrate of soda, 80 lbs. mur. pot.
Pots 97 and 98, 320 lbs. acid phos., 80 lbs. mur. pot., 160 lbs. nit. soda.
Pots 99 and 100, 640 lbs. acid phos., 80 lbs. mur. pot., 160 lbs. nit. soda.
Pots 101 and 102, 640 lbs. acid phos., 80 lbs. mur. pot., 320 lbs. nit. soda.
Pots 105 and 106, 320 lbs. acid phos., 80 lbs. mur. pot., 640 lbs. nit. soda.
Pots 107 and 108, 10 tons manure.
Pots 109 and 110, 20 tons manure.

The fertilizing materials were thoroughly incorporated in the top three inches of soil. The stable manure was mixed with the entire bulk of soil.

On November 29 all pots were planted to Kherson oats and the soil brought to its proper moisture content, as previously outlined. In planting the following method was used: Each pot in a series received one kernel from the same panicle, as many panicles being used as there were kernels in a pot. This was to avoid any difference in the growth of plants in the different pots due to the individuality of the plant from which the seed was taken. A good germination was secured and on December 31 the plants were thinned, leaving eight plants per pot. On January 1 550 grams of finely crushed quartz were placed over the surface of the soil in each pot, to act as a mulch.

### *Effect of Moisture and Fertilizers Upon the General Development and Appearance of the Plants.*

*Series 1 (Old Series).*—After the plants had grown for two months it was quite evident that the fertilizers were producing results very different from those produced upon this same soil in the previous test. It will be remembered that phosphorus produced the greatest increase in yield as a result of the first test. Where the same combinations and amounts of fertilizing materials have been added to these same pots one year later, the nitrogen is most effective in producing growth, while in some cases the phosphorus was even dwarfing the plants, and in all cases where either phosphorus or potash was added singly or in combination with each other, there was a marked tendency for the plants to turn yellow and possess, in general, an unhealthy appearance. Where nitrogen was added, either alone or in combination with the mineral elements, the growth of plants was much increased, and their general appearance was green, vigorous and healthy. The stable manure produced an increased growth of plants, though this was not very marked.

*Series 2—Moisture 17.6 Percent.*—In this series the plants were very much smaller than in series 1, 3 and 4, but were of good color and appeared quite healthy. The acid phosphate and muriate of potash seemed, at this time (Feb. 10), to be producing very much more beneficial results in this series than in series 1. There seemed to be no tendency upon the part of the plants receiving mineral fertilizers to turn yellow and dry up, as they did in other series, notably series 1. The single application of acid phosphate to this low-moisture soil, had, at this time, produced a marked increase in the growth of the plants. The muriate of potash had produced a slight increase, but not so much as the acid phosphate. However, the best results were obtained where a complete fertilizer was added, pots 45 and 46 receiving a maximum amount of acid phosphate, and pots 49 and 50 receiving a maximum amount of sodium nitrate, producing the most vigorous growth. The applications of 10 and 20 tons of manure, respectively, produced an increase in the growth of plants, though not so much as the complete fertilizers. The plants in the pots receiving the manure at the rate of 20 tons per acre were slightly better than those to which 10 tons had been applied.

*Series 3—Moisture Content 29.0 Percent.*—Here the growth was about equal in pots receiving respectively, no treatment, 320 lbs. acid phosphate, and 80 lbs. muriate of potash. In pots 61 and 62 where nitrate of soda was added at the rate of 160 lbs. per acre a fair increase in growth was secured, as was also true as regards pots 63 and 64, receiving 320 lbs. acid phosphate and 160 lbs. nitrate of soda per acre. Where acid phosphate and muriate of potash were combined without nitrogen, very little increase in growth was produced. The most vigorous growth in the series was produced where a complete fertilizer was added, reaching its maximum where the largest amounts of nitrogen were added. In this series the plants in the pots which received stable manure at the rate of 10 tons per acre were making a better growth than where the larger amount of manure was added.

*Series 4—Moisture Content 42.8 Percent.*—In general the growth of plants in this series was slightly better than in either series 1 or 3, and much better than in series 2. The growth seemed about the same in pots 85 and 86 (320 lbs. acid phos.), 87 and 88 (80 lbs. mur. pot.), 89 and 90 (160 lbs. nit. soda), 91 and 92 (320 lbs. acid phos., 160 lbs. nit. soda), and 95 and 96 (160 lbs. nit. soda, 80 lbs. mur. pot.). These were all slightly better than no treatment. Pots 93 and 94 (320 lbs. acid phos., 80 lbs. mur. pot.) were hardly as good as the checks. The most luxuriant growth in the series was produced in pots 105 and 106, which received nitrate of soda at the rate of 640 lbs. per acre together with 320 lbs. of acid phosphate and 80 lbs. muriate of potash. The stable manure had not produced a very marked increase in growth. The plants in pot 109 were very much dwarfed from some unaccountable reason.

By the latter part of February the plants in series 1, 3 and 4 were rather badly affected with "red leaf." The tendency toward affection seemed to be in direct relation to the treatment, the acid phosphate and muriate of potash increasing it while the nitrate of soda rendered the plants somewhat resistant. Stable manure also had a tendency to increase the affection.

In series 1, the worst affected plants were those growing in pots 3 and 4 (320 lbs. acid phosphate) and 11 and 12 (320 lbs. acid phosphate, 80 lbs. muriate potash) while all plants to which acid phosphate and muriate of potash were added were more or less affected. Plants in pots 1 and 2 (no treatment), 7 and 8 (160 lbs. nitrate soda), were not affected.

In series 2, the plants were very slightly affected, the low soil moisture seemingly increasing their power of resistance. However, where acid phosphate and muriate of potash were added without nitrogen, or where acid phosphate occurred in maximum amounts, this malady was present, though not serious.

In series 3 and 4, the same conditions existed as in series 1, though hardly so marked.

### *Effect of Soil Moisture and Fertilizers Upon Time of Heading.*

It was observed that the length of the period from planting to heading was to a certain extent influenced by the soil moisture content and also by the fertilizers. The tendency of the plants toward stooling was likewise influenced by these factors. Unfortunately some of the panicles were infected with smut which, to a certain extent, diminished the yield in these pots.

Table II shows the influence of the soil moisture and the fertilizers upon the period of heading. See also Fig. 17.

TABLE II.—*Showing Soil Treatments and Number of Days from Planting to Heading for the Different Moisture Contents.*

| Treatment. | Days from Planting to Heading. | | | |
|---|---|---|---|---|
| | 17.6 Percent W. | 29.0 Percent W. | 42.0 Percent W. | Average. |
| No treatment | 128.0 | 123.0 | 128.0 | 126.3 |
| 320 P* | 123.0 | 122.0 | 126.0 | 123.6 |
| 80 K | 121.0 | 124.0 | 124.0 | 123.0 |
| 160 N | 117.5 | 121.5 | 120.5 | 119.6 |
| 320 P, 160 N | 119.0 | 120.5 | 125.0 | 121.5 |
| 320 P, 80 K | 122.0 | 123.0 | 124.0 | 123.0 |
| 160 N, 80 K | 116.5 | 118.5 | 122.0 | 119.0 |
| 320 P, 80 K, 160 N | 122.5 | 117.5 | 121.5 | 120.5 |
| 640 P, 80 K, 160 N | 121.0 | 118.5 | 123.0 | 120.8 |
| 640 P, 80 K, 320 N | 116.0 | 119.5 | 123.0 | 119.5 |
| 320 P, 80 K, 320 N | 114.5 | 120.0 | 119.5 | 118.0 |
| 320 P, 80 K, 640 N | 115.0 | 111.0 | 112.0 | 112.6 |
| 10 tons manure | 124.5 | 119.0 | 125.0 | 122.8 |
| 20 tons manure | 128.0 | 118.0 | 126.0 | 124.0 |
| Average | 120.6 | 119.7 | 122.8 | |

* P = acid phosphate; K = muriate potash; N = nitrate of soda.

The length of time required for the plants to reach the stage of heading has been shortened 0.9 of a day following an increase in soil moisture from 17.6 to 29.0 percent, while an increase in moisture from 29.0 percent to 42.8 percent has increased this period practically two days over that of 17.6 percent moisture and three days over that

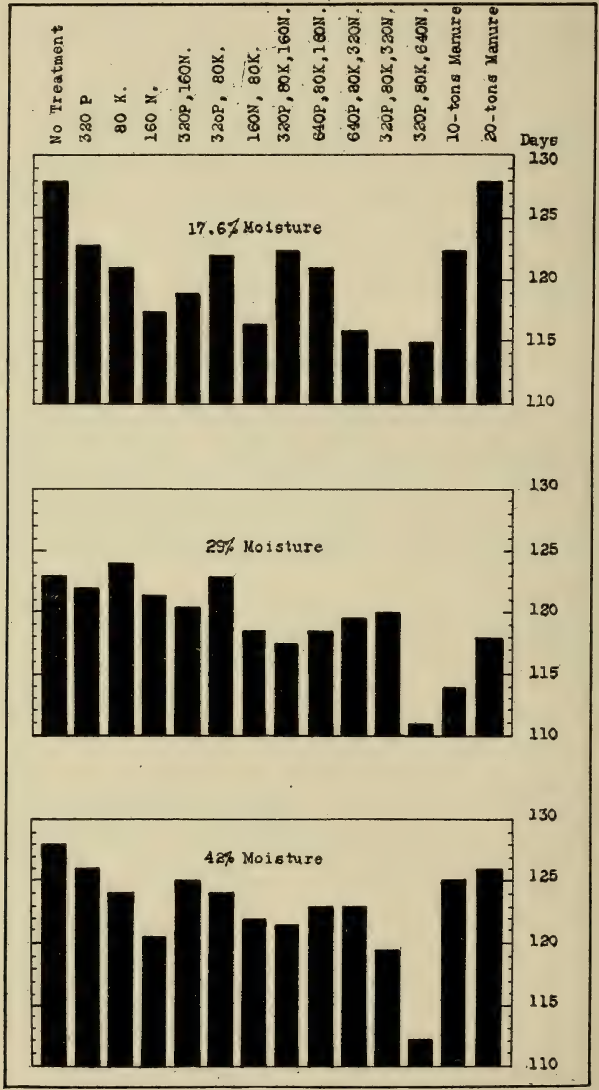

FIG. 17.—Number of days from planting to heading, under the different conditions of soil moisture and fertilization (oats).

of 29.0 percent moisture. The moisture content of the soil apparently has influenced the length of this stage of growth some, but not nearly so much as have the fertilizers. We find that the greatest average variation in the length of time required for the plants to reach the heading stage following the changes in the moisture content of the soil, is approximately three days, while the fertilizers have produced a change in this period of approximately fourteen days, varying from an average of 112.6 where the maximum amounts of nitrogen were added to an average of 126.3 days where no treatment was given. It is quite evident that all of the fertilizing materials have had a tendency to shorten this period of growth, as there is only one case where plants in a treated pot have grown a longer time before heading than the plants in the untreated pots of similar soil moisture conditions. This exception is found in the 29.0 percent moisture series where the single application of muriate of potash was made. Nitrate of soda was by far more effective in hastening the heading period than either potash or phosphoric acid. The effect of fertilizers seems to have been more marked in the high than in the low soil moisture (Fig. 17).

### *Effect of Moisture and Fertilizers Upon the Stooling of Plants.*

The tendency of the plants toward stooling is very strongly influenced by both the soil moisture and fertilizers. This is quite evident from Table III. See also Fig. 18.

TABLE III.—*Showing the Influence of Soil Moisture and Fertilizers Upon the Stooling of Plants (Oats).*

| Treatment. | 17.6 Percent W. | | 29.0 Percent W. | | 42.8 Percent W. | | Average Percent. |
|---|---|---|---|---|---|---|---|
| | Number Stooling. | Percent. | Number Stooling. | Percent. | Number Stooling. | Percent. | |
| No treatment | 4 | 25.0 | 0 | 0 | 0 | 0 | 8.33 |
| 320 P | 3 | 18.7 | 0 | 0 | 0 | 0 | 6.23 |
| 80 K | 2 | 12.5 | 0 | 0 | 0 | 0 | 4.16 |
| 160 N | 7 | 43.7 | 4 | 25.0 | 0 | 0 | 22.90 |
| 320 P, 160 N | 5 | 31.2 | 2 | 12.5 | 3 | 18.7 | 20.80 |
| 320 P, 80 K | 3 | 18.7 | 2 | 12.5 | 0 | 0 | 10.40 |
| 160 N, 80 K | 7 | 43.7 | 3 | 18.7 | 0 | 0 | 20.80 |
| 320 P, 80 K, 160 N | 9 | 56.2 | 1 | 6.2 | 0 | 0 | 20.80 |
| 640 P, 80 K, 160 N | 9 | 56.2 | 1 | 6.2 | 0 | 0 | 20.80 |
| 640 P, 80 K, 320 N | 12 | 75.0 | 5 | 31.2 | 2 | 12.5 | 39.50 |
| 320 P, 80 K, 320 N | 11 | 68.7 | 14 | 87.5 | 3 | 18.7 | 58.30 |
| 320 P, 80 K, 640 N | 16 | 100.0 | 16 | 100.0 | 13 | 81.2 | 93.70 |
| 10 tons manure | 2 | 12.5 | 2 | 12.5 | 0 | 0 | 8.33 |
| 20 tons manure | 1 | 6.2 | 3 | 18.7 | 0 | 0 | 8.33 |
| Average | 6.5 | 40.6 | 3.8 | 23.7 | 1.3 | 8.1 | |

Increasing the moisture content of the soil from 17.6 percent to 42.8 percent has decreased the stooling of the plants from 40.6 percent to 8.1 percent. This seems quite strange, as it would be expected that, other things being equal, an increase in the soil moisture would tend to increase the tendency of the plants to stool. The results,

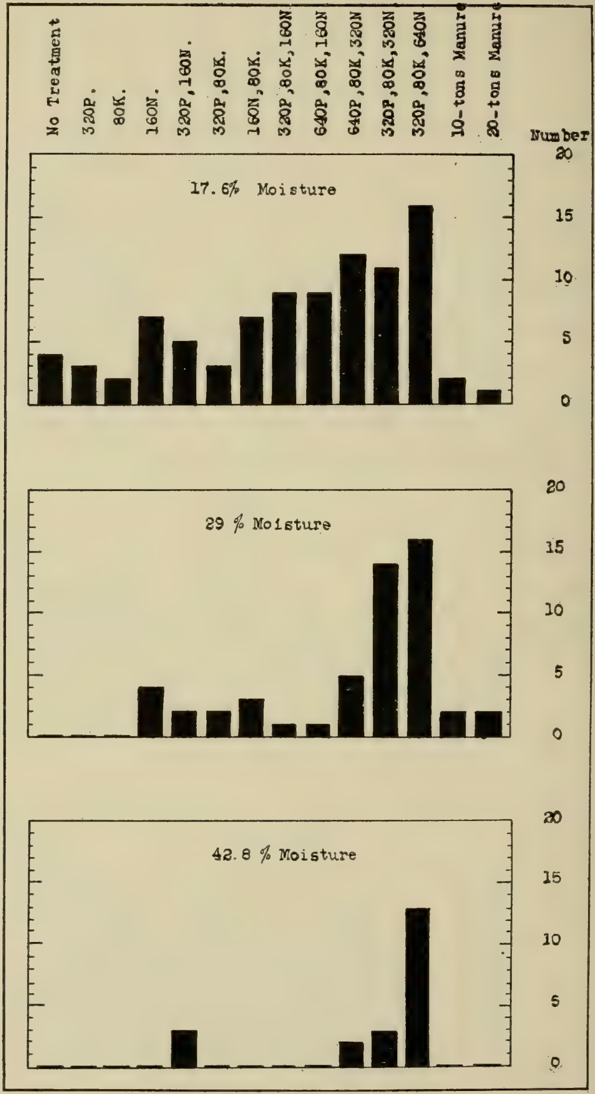

FIG. 18.—Influence of soil moisture and fertilizers on the stooling of plants (oats).

however, are quite consistent, showing in low moisture 40.6 percent stooling, in medium moisture 23.7 percent, and in high moisture 8.1 percent.

The fertilizers have also had a very marked influence upon the plants in this respect. This is not very noticeable with regard to the mineral fertilizers, but the effect of the nitrogen is very striking. Taking an average of the three series of plants, we find that there is an increase in the percentage of plants stooling, from 8.33 where no treatment was given, to 93.70 where the maximum amounts of nitrogen were added. The tendency of the plants to stool is in direct relation to the amount of nitrogen supplied. However, the proportion of nitrogen to phosphorus is also important. Nitrogen combined with large amounts of phosphorus does not produce as marked effect as when combined with smaller amounts. It is also quite evident, from the table, that nitrogen has been relatively more effective, as regards the stooling of the plants, in the low than in the high soil moisture. Its effect gradually and consistently decreases as the moisture content of the soil increases.

In making the preceding comparisons as regards moisture and fertilizers, as they affect the period of growth and also the tendency of the plants to stool, series 1 has been omitted because the soil in this test is not altogether comparable with that in the other 3 series, owing to the fact that the soil for the former series had grown one crop of plants in the greenhouse, to which fertilizers had been added, while the soil for the remaining series had been in the greenhouse for only a short time and had received no previous fertilization. The data for series 1, as regards the properties under discussion, will be found in Table IV.

Table IV.—*Showing Number of Days from Planting to Heading and Number and Percent of Plants Stooling, Series 1—Moisture 33.3 Percent.*

| Treatment. | Days from Planting to Heading. | No. of Plants Stooling. | Percent of Plants Stooling. |
|---|---|---|---|
| No treatment | 119.5 | 6 | 37.5 |
| 320 P | 122.5 | 0 | 0.0 |
| 80 K | 118.0 | 1 | 6.2 |
| 160 N | 116.0 | 7 | 43.7 |
| 320 P, 160 N | 116.0 | 1 | 6.2 |
| 320 P, 80 K | 120.5 | 0 | 0.0 |
| 160 N, 80 K | 115.0 | 8 | 50.0 |
| 320 P, 80 K, 160 N | 118.0 | 2 | 12.5 |
| 640 P, 80 K, 160 N | 117.0 | 3 | 18.7 |
| 640 P, 80 K, 320 N | 111.5 | 11 | 68.7 |
| 320 P, 80 K, 320 N | 112.5 | 10 | 62.5 |
| 10 tons manure | 117.5 | 4 | 25.0 |
| 20 tons manure | 119.0 | 4 | 25.0 |
| Average | 117.1 | 4.4 | 27.4 |

In this series the mineral fertilizers, especially the acid phosphate, have influenced the length of the period from planting to heading in a somewhat different way from what they did in series 2, 3 and 4. In series 1, the acid phosphate, when added alone or in combination with muriate of potash, has slightly increased the length of this period of growth, this also being coupled with a decreased growth. In series 2, 3 and 4 this same combination of fertilizers has decreased the number of days from planting to heading, this being associated with an increased yield. As has been previously stated, the mineral fertilizers, either alone or in combination, seemed to check the growth of plants in series 1, while in the other series their action was generally beneficial.

The percentage of plants stooling in the 33.3 percent moisture series is greater than in the 29.0 percent moisture, but is much less than in the 17.6 percent moisture series. Nitrogen has here, as in the other series, been the active agent in inducing the plants to stool.

### *Effect of Moisture and Fertilizers Upon Yield.*

It was decided to harvest the plants as soon as they were fully headed, the main object being to determine the effect of the fertilizers, under the different conditions of soil moisture, upon the total production of dry matter, and also upon the chemical nature of the dry matter as regards nitrogen. In order that all plants should be harvested at the same stage of maturity, it was decided to harvest the plants in

TABLE V.—*Showing Effect of Soil Moisture and Fertilizers Upon the Production of Green Weights and Dry Matter in Plants (Grams).*

| Treatment. | 17.6 Percent W. | | 29.0 Percent W. | | 42.8 Percent W. | |
|---|---|---|---|---|---|---|
| | Gr. Wt. | Dry Wt. | Gr. Wt. | Dry Wt. | Gr. Wt. | Dry Wt. |
| No treatment | 12.400 | 6.333 | 29.970 | 11.714 | 47.300 | 15.581 |
| 320 P | 23.900 | 8.907 | 36.400 | 11.881 | 45.450 | 14.928 |
| 80 K | 20.000 | 7.101 | 33.400 | 12.361 | 56.650 | 16.530 |
| 160 N | 32.220 | 11.349 | 47.220 | 20.114 | 67.190 | 20.700 |
| 320 P, 160 N | 43.100 | 14.917 | 69.110 | 22.628 | 60.275 | 22.077 |
| 320 P, 80 K | 21.450 | 8.759 | 39.890 | 12.275 | 49.050 | 13.748 |
| 160 N, 80 K | 46.770 | 12.640 | 47.825 | 18.219 | 58.950 | 19.882 |
| 320 P, 80 K, 160 N | 43.570 | 15.418 | 53.695 | 16.657 | 67.220 | 20.908 |
| 640 P, 80 K, 160 N | 41.850 | 15.926 | 49.400 | 20.326 | 68.775 | 22.269 |
| 640 P, 80 K, 320 N | 62.125 | 21.688 | 59.190 | 20.733 | 59.440 | 19.711 |
| 320 P, 80 K, 320 N | 71.670 | 21.228 | 90.300 | 30.346 | 68.750 | 21.547 |
| 320 P, 80 K, 640 N | 106.050 | 27.974 | 135.275 | 37.662 | 134.525 | 40.245 |
| 10 tons manure | 17.550 | 8.388 | 37.900 | 14.258 | 49.650 | 18.064 |
| 20 tons manure | 26.400 | 10.371 | 45.620 | 11.758 | 47.800 | 16.927 |
| Average | 40.647 | 13.642 | 55.371 | 18.638 | 62.930 | 20.222 |

each pot just twenty days after the first heads appeared. This plan was followed in harvesting all of the plants in the four series. Table V gives the green and dry weights of plants produced under the different conditions. See also Fig. 19.

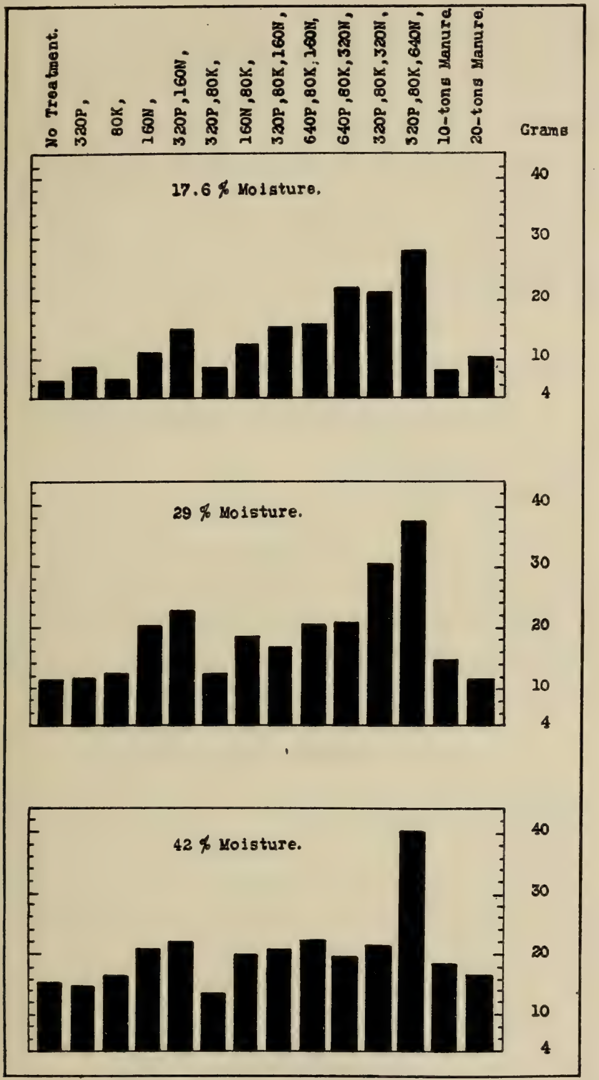

FIG. 19.—Production, in grams of dry matter, under different conditions of soil moisture and fertilization.

It will be noticed in Table V that the green weights of the plants do not, in every instance, give the same indications as regards yield as do the dry weights. For example, in 17.6 percent soil moisture, where fertilizers were added at the rate of 160 lbs. nitrate of soda and 80 lbs. muriate of potash per acre, the green weight of the plants indicates a higher yield than was gotten from the following treatment where 320 lbs. acid phosphate were added in connection with the nitrate and potash. However, when the dry weight is considered, we get the opposite indications, namely, a lower yield where the former treatment was given. The same treatments in the 29.0 percent moisture soils also show conflicting indications. These differences as indicated by green and dry weights occur most frequently where large amounts of acid phosphate or nitrate of soda were added, and are, of course, due to variations in the moisture content of the plants grown under the different conditions of fertilization. The effect of the fertilizers and moisture upon the percentage dry matter in green weight will be discussed later. In considering the effect of fertilizers upon yield, the dry matter will, in every case, be taken as the criterion of growth.

Table VI.—*Showing Influence of Nitrogenous and Mineral Fertilizers Upon the Relation of Moisture to Yield.*

| | N-Fert. | Mineral Fert. |
|---|---|---|
| 17.6 percent to 29.0 percent ................ | 5.69 | 4.28 |
| 29.0 percent to 42.8 percent ................ | 0.82 | 3.14 |

Table VII.—*Showing Increase in Grams, and Percent Increase in Dry Matter Due to Fertilizer Treatments Under Different Conditions of Soil Moisture.*

| Treatment. | 17.6 Percent W. Grams. | Percent. | 29.0 Percent W. Grams. | Percent. | 42.8 Percent W. Grams. | Percent. |
|---|---|---|---|---|---|---|
| No treatment....... | X | X | X | X | X | X |
| 320 P.............. | 2.574 | 40.64 | 0.167 | 1.43 | −0.653 | − 4.19 |
| 80 K.............. | 0.768 | 12.13 | 0.647 | 5.52 | 0.949 | 6.09 |
| 160 N.............. | 5.016 | 79.20 | 8.400 | 71.70 | 5.119 | 32.85 |
| 320 P, 160 N....... | 8.584 | 135.60 | 10.914 | 93.20 | 6.496 | 41.68 |
| 320 P, 80 K....... | 2.426 | 38.31 | 0.561 | 4.79 | −1.833 | −11.76 |
| 160 N, 80 K....... | 6.307 | 99.60 | 6.505 | 55.53 | 4.301 | 27.60 |
| 320 P, 80 K, 160 N | 9.085 | 143.40 | 4.943 | 42.20 | 5.327 | 34.19 |
| 640 P, 80 K, 160 N | 9.593 | 151.40 | 8.612 | 73.52 | 6.688 | 42.91 |
| 640 P, 80 K, 320 N | 15.355 | 242.40 | 9.019 | 77.00 | 4.130 | 26.50 |
| 320 P, 80 K, 320 N | 14.895 | 235.10 | 18.632 | 159.00 | 5.966 | 38.28 |
| 320 P, 80 K, 640 N | 21.641 | 341.70 | 25.948 | 221.40 | 24.664 | 158.30 |
| 10 tons manure..... | 2.055 | 32.45 | 2.544 | 21.72 | 2.483 | 15.93 |
| 20 tons manure..... | 4.038 | 63.76 | 0.044 | 00.37 | 1.346 | 8.64 |
| Average........... | 7.872 | 124.28 | 7.456 | 63.64 | 5.000 | 32.08 |

There is an increase in the production of dry matter following an increase in the moisture content of the soil. The increase is more marked following a change in moisture from 17.6 to 29.0 percent than

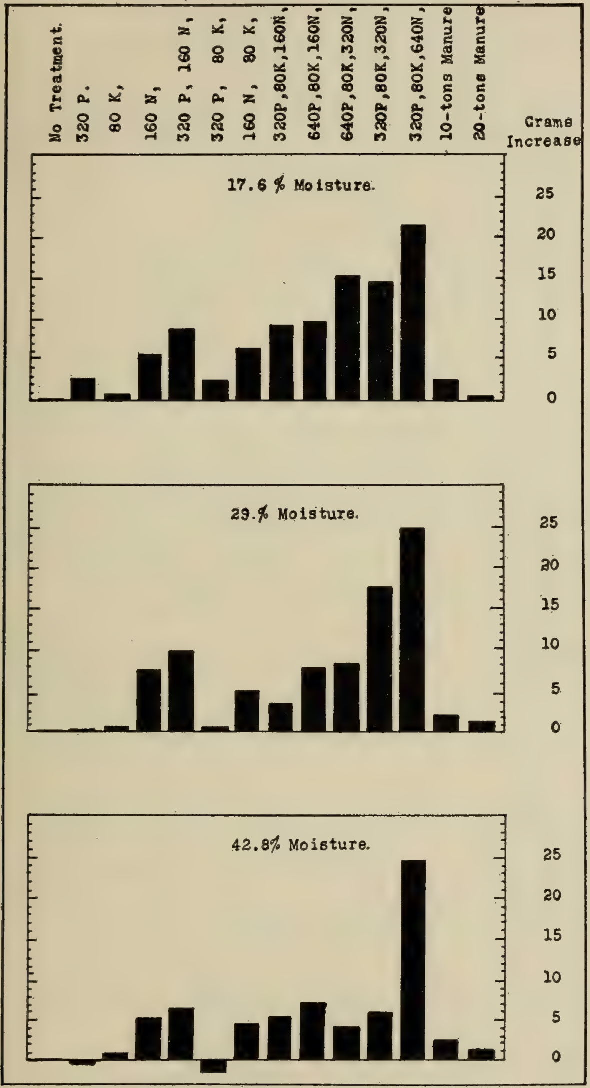

FIG. 20.—Increase, in grams of dry matter, due to fertilizer treatments, under different conditions of soil moisture (oats).

from 29.0 to 42.8 percent. It will be also seen that the increase in moisture from low to medium produced a greater increase in yield following the application of nitrogenous fertilizers than mineral fertilizers, while the greater yield occurred following the application of mineral fertilizers when the moisture was increased from medium to large amounts. This is shown in Table VI.

It is also quite evident that the fertilizers have produced a relatively greater increased yield in the low than in the high soil moisture. This is shown in Table VII and in Fig. 20.

All fertilizers, both mineral and nitrogenous, have greatly decreased in their relative efficiency following an increase in soil moisture. The decrease is quite consistent. In the 17.6 percent moisture soil the average increase in dry matter over that of no treatment for all kinds and combinations of fertilizers, has been 7.872 grams, or 124.28 percent; for 29.0 percent moisture soil this increase was 7.456 grams or 63.64 percent, and in the high moisture soil an increase of 5.0 grams or only 32.08 percent was produced. While the actual amounts of increase in dry matter due to the fertilizers did not decrease very markedly, especially where the soil moisture was changed from low to medium, the percentage increase became rapidly less, owing to the decided effect which the larger amounts of soil moisture exerted in increasing the yield. If we consider the untreated pots, we will see that as larger amounts of soil moisture were added the production of dry matter became considerably greater, causing the percentage increase due to fertilizers to rapidly decrease.

### *Influence of Moisture Upon the Action of Fertilizers.*

The behavior of the different fertilizing materials under the varying moisture conditions is quite different. In every case the lowest yield from any of the treated pots was obtained where mineral fertilizers alone were added. In order to bring out, if possible, the relation between the effects of the different plant food constituents, under the three moisture conditions, the following calculations were made, taking in every case as 100, the increase or decrease produced by the no-nitrogen fertilizers. Table VIII gives the results:

TABLE VIII.—*Showing Relative Effects of Different Fertilizers Under Different Conditions of Moisture.*

| | Percent Increase of No-N Fert.= 100. | | |
|---|---|---|---|
| | 17.6 Percent W. | 29.0 Percent W. | 42.8 Percent W. |
| PK | 100.00 | 100.00 | 100.00 |
| $PKN_2$ | 376.54 | 1,680.89 | 14,620.00 |
| KN | 209.37 | 1,132.70 | 9,515.22 |
| $P_2KN$ | 294.41 | 906.24 | 6,426.42 |
| PN | 280.14 | 1,419.26 | 10,060.05 |
| $PK_2N$ | 241.32 | 691.45 | 6,018.87 |

Assuming the effects of the mineral fertilizers, when added alone, to be 100 percent for the three different moisture contents, the high nitrogen fertilizers have produced, in the 17.6 percent moisture soil, an increased yield of more than three and two thirds times as much as that of mineral fertilizers alone, while in the 29.0 percent moisture soil this increase due to nitrogen was more than sixteen times as much as for the minerals, and in the high moisture soil more than one hundred and forty-six times that of the mineral fertilizers. This does not signify that the nitrogenous fertilizers have been more effective in the high than in the low moisture soil, for such is not the case. It does show, however, that as compared with mineral fertilizers, the efficiency of the nitrogen has rapidly increased, following an increase in soil moisture. This is largely due to the fact that as the soil moisture increased, the mineral fertilizers decreased in efficiency very much more rapidly than did the nitrogenous fertilizers, as is shown by the fact that where the moisture content of the soil was 42.8 percent the mineral fertilizers, when added alone, actually decreased the yield.

Where maximum amounts of phosphorus and potash were added in connection with minimum amounts of nitrogen we find that the increased yield produced, as compared with that of minerals only, became greater as the moisture content of the soil increased, but not nearly so rapidly as where *large* amounts of nitrogen were added. That the effects of these fertilizers did increase with the soil moisture was undoubtedly due to the nitrogen present. It appears that the potash did not decrease in efficiency, following a rise in the moisture content of the soil, so rapidly as did the phosphoric acid.

TABLE IX.—*Showing Effect of Fertilizers Upon Yield Where 33.3 Percent Moisture was Maintained in the Soil.*

| Treatment. | Green Weight. | Dry Weight. | Percent Dry Matter. | Increase or Decrease. | Percent Increase or Decrease. |
|---|---|---|---|---|---|
| No treatment | 36.700 | 11.791 | 32.1 | X | X |
| 320 P | 24.920 | 8.562 | 36.4 | −3.229 | −27.4 |
| 80 K | 33.640 | 9.469 | 28.2 | −2.322 | −19.7 |
| 160 N | 56.070 | 15.910 | 28.4 | 4.119 | 34.9 |
| 320 P, 160 N | 47.700 | 15.538 | 32.6 | 3.747 | 31.8 |
| 320 P, 80 K | 26.340 | 7.756 | 29.4 | −4.035 | −34.2 |
| 160 N, 80 K | 64.120 | 19.978 | 31.1 | 8.187 | 69.4 |
| 320 P, 80 K, 160 N | 41.700 | 16.189 | 38.8 | 4.398 | 37.3 |
| 640 P, 80 K, 160 N | 47.400 | 17.319 | 36.6 | 5.528 | 46.9 |
| 640 P, 80 K, 320 N | 77.800 | 23.118 | 29.7 | 11.327 | 96.0 |
| 320 P, 80 K, 320 N | 90.325 | 26.011 | 28.8 | 14.220 | 120.5 |
| 10 tons manure | 46.220 | 15.802 | 34.2 | 4.011 | 34.0 |
| 20 tons manure | 42.100 | 15.849 | 37.6 | 4.058 | 34.6 |

In the 33.3 percent moisture series, the mineral fertilizers produced an even greater decrease in yield than where 42.8 percent moisture was maintained. This, however, was the second application of fertilizers which the former series had received and there was likely a residual effect as a result of the first treatment. Table IX gives the data for this series:

In every case where mineral fertilizers have been added without nitrogen the yield has been decreased. This seems still more peculiar when we remember that this same soil one year previous to this test gave its best yields where rather large amounts of mineral fertilizers, especially phosphoric acid, were applied. The nitrogenous fertilizers have produced, in this series as in the others, a very creditable yield.

### *Effect of Soil Moisture and Fertilizers Upon the Percentage Dry Matter in Plants.*

Table X has been arranged to show to what extent the moisture content of the soil and also the fertilizers have influenced the percentage of dry matter in the plants. All plants were harvested twenty days from heading, hence, should have reached approximately the same stage of maturity, though the moisture and fertilizers would doubtless influence, to a certain extent, the length of time from heading to complete maturity.

TABLE X.—*Showing Effect of Soil Moisture and Fertilizers Upon the Percentage Dry Matter in Plants.*

| Treatment. | Percent Dry Matter in Crop. | | | |
|---|---|---|---|---|
| | 17.6 Percent W. | 29.0 Percent W. | 42.8 Percent W. | Average. |
| No treatment | 51.1 | 39.1 | 32.9 | 41.03 |
| 320 P | 37.3 | 32.6 | 32.8 | 34.23 |
| 80 K | 35.5 | 37.0 | 29.2 | 33.90 |
| 160 N | 35.2 | 42.6 | 30.8 | 36.20 |
| 320 P, 160 N | 34.6 | 32.8 | 36.6 | 34.66 |
| 320 P, 80 K | 40.9 | 30.8 | 28.0 | 33.23 |
| 160 N, 80 K | 27.0 | 38.1 | 33.7 | 32.93 |
| 320 P, 80 K, 160 N | 35.4 | 31.0 | 31.1 | 32.50 |
| 640 P, 80 K, 160 N | 38.0 | 41.1 | 32.4 | 37.16 |
| 640 P, 80 K, 320 N | 34.9 | 35.0 | 33.2 | 34.36 |
| 320 P, 80 K, 320 N | 29.6 | 33.6 | 31.4 | 31.53 |
| 320 P, 80 K, 640 N | 26.4 | 27.9 | 29.9 | 28.06 |
| 10 tons manure | 47.8 | 37.6 | 36.4 | 40.60 |
| 20 tons manure | 39.3 | 25.8 | 35.4 | 33.50 |
| Average | 36.6 | 34.6 | 32.3 | |

The percentage of dry matter in the plants is variable, but, in the main, decreases following an increase in the moisture content of the soil. (See Fig. 21.) Where maximum amounts of nitrogen were added the percent of dry matter is very decidedly decreased. Smaller amounts of nitrogen have not very materially affected the relation of

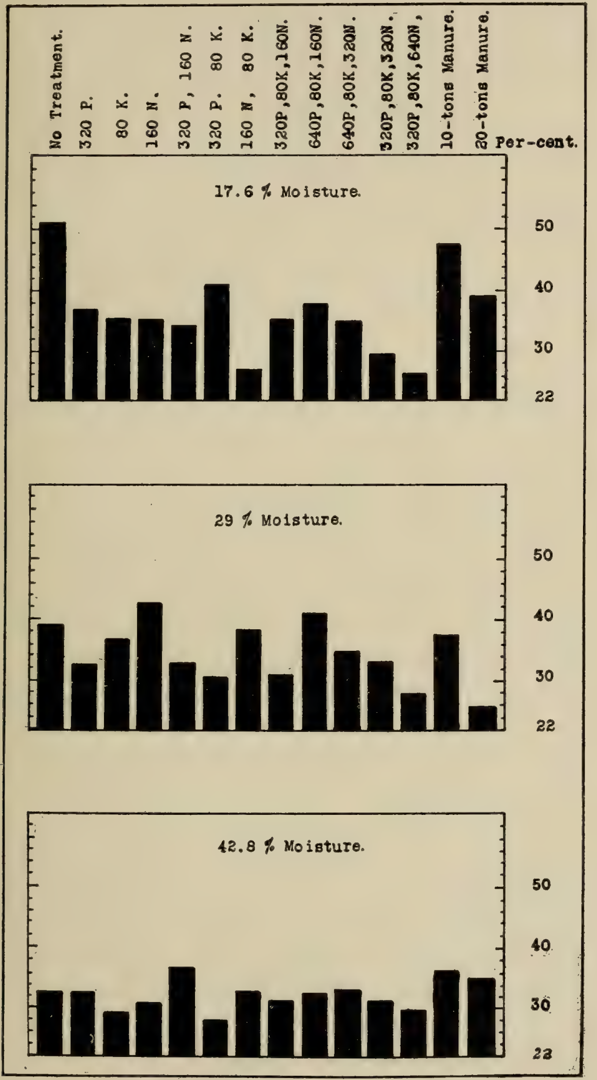

FIG. 21.—Per cent. of dry matter in plants (oats) under different conditions of soil moisture and fertilization.

green to dry weight of plants. It is difficult to trace any relation between the mineral fertilizers and the percent of dry matter in plants, other than that where very large applications of phosphorus were made with a minimum amount of nitrogen, the dry matter was quite high. Generally speaking, where the yield was relatively low, the percentage dry matter in the plants was relatively high and vice versa. Where no treatment was given the percentage dry matter gradually decreased following an increase in soil moisture.

## The Wire Basket Test.

All of the pot treatments, as regards both moisture and fertilizers, were duplicated in small paraffined wire baskets. These baskets were three inches deep by three inches in diameter and were constructed of wire gauze having eight meshes per inch. Into each basket was put 315 grams of soil (same soil as was used in pot test) and this was thoroughly coated with paraffin by dipping each basket when filled into a bucket of melted paraffin. Five of these baskets constituted a group, there being as many groups as there were treatments to be made. Each group corresponded to a treatment given to the pots, i. e., group 27 received the same treatment as pots 27 and 28, group 29 the same treatment as pots 29 and 30, etc. The combination of fertilizers added and the rates per acre were exactly the same as those for the pot tests. After the treatments were given, eight oat kernels, of the same variety used in the pot test, were planted in a row in each basket. When these were up one to one and one half inches above ground they were thinned to five plants per basket and the baskets sealed. This was done by cutting a paper disc to fit in the basket over the soil, small openings being left in the disc through which the plants were to grow. The disc was then dipped in melted paraffin and placed over the soil in such a manner as not to injure the plants. By means of running a small amount of paraffin around the edges of the disc, it was made perfectly tight. This, together with a layer of finely ground quartz, which had been placed over the soil before the basket was sealed, prevented any moisture from escaping from the soil, other than that which was transpired by the plants. Careful weights were kept of the baskets, both before and after sealing, and as a moisture determination of the soil was made at the time the baskets were filled it was possible to accurately maintain the soil moisture at any content desired.

There were 210 of these baskets. They were divided into three series to correspond with series 2, 3 and 4 of the pot test. Each series contained fourteen groups and each group contained five baskets. The soil moisture in series 2 was maintained at 17.6 percent; in series 3, at 29.0 percent; in series 4, at 42.8 percent.

The baskets were weighed every three days for three weeks. The amount of moisture which had been transpired by the plants at each weighing was carefully recorded and the same amount of distilled water added. At the end of the three weeks the plants were harvested and green and dry weights for each group determined.

Of course it is obvious that results obtained by means of the wire-basket test are not to be relied upon to the same extent as those obtained from the pots, for the reason that the baskets furnish evidence extending over a very small portion of the plant's life history, whereas the pot method gives the results of plant growth from planting to maturity. However, it is believed that valuable indications may be obtained from the basket method.

It is also incorrect to regard either transpiration or green weight of plants as a criterion of growth, as neither one bears a constant relation to the production of dry matter. In Tables XI, XII and XIII, transpiration, green weights, and dry weight of plants will be considered separately, though in drawing final conclusions only the dry matter produced will be considered.

TABLE XI.—*Showing Total Transpiration and Percentage Increase or Decrease (—) in Transpiration Due to Fertilizers.*

| Treatment. | 17.6 Percent W. | | 29.0 Percent W. | | 42.8 Percent W. | | Average. Increase or Decrease Percent. |
|---|---|---|---|---|---|---|---|
| | Trans. (Grams). | Percent Increase or Decrease. | Trans. (Grams). | Percent Increase or Decrease. | Trans. (Grams). | Percent Increase or Decrease. | |
| No treatment | 461.3 | X | 557.0 | X | 714.0 | X | X |
| 320 P | 397.9 | −13.5 | 512.6 | − 7.6 | 654.5 | − 8.3 | − 9.80 |
| 80 K | 451.2 | − 2.2 | 595.5 | 6.9 | 673.0 | − 5.7 | − 0.33 |
| 160 N | 518.9 | 12.5 | 694.4 | 24.7 | 739.6 | 3.6 | 13.60 |
| 320 P, 160 N | 437.6 | − 5.1 | 666.3 | 19.6 | 797.2 | 11.7 | 8.73 |
| 320 P, 80 K | 419.9 | − 8.9 | 481.5 | −13.6 | 577.4 | −19.1 | −13.86 |
| 160 N, 80 K | 500.3 | 8.4 | 670.4 | 20.4 | 730.0 | 2.2 | 10.33 |
| 320 P, 80 K, 160 N | 458.5 | − 2.8 | 527.7 | − 5.3 | 704.1 | − 1.4 | − 3.16 |
| 640 P, 80 K, 160 N | 452.3 | − 1.9 | 582.1 | 4.5 | 697.2 | − 2.4 | 0.06 |
| 640 P, 80 K, 320 N | 465.5 | .9 | 641.9 | 15.2 | 790.3 | 10.3 | 8.80 |
| 320 P, 80 K, 320 N | 469.8 | 1.8 | 624.5 | 12.1 | 827.5 | 15.8 | 9.90 |
| 320 P, 80 K, 640 N | 471.2 | 2.1 | 741.7 | 33.1 | 957.1 | 34.0 | 23.06 |
| 10 tons manure | 364.3 | −21.0 | 419.6 | 24.7 | 616.0 | −13.7 | 3.33 |
| 20 tons manure | 351.7 | −23.8 | 513.7 | − 7.8 | 635.0 | 11.7 | 6.63 |
| Average | 444.3 | − 4.1 | 587.7 | 9.76 | 722.3 | 2.93 | 4.32 |

Where the moisture content of the soil was maintained at 17.6 percent the fertilizers have produced an average decrease in transpiration, for the entire series, of 4.1 percent. The maximum amount of nitrogen has produced, in this low moisture soil, an increased transpiration of only 2.1 percent. Wherever the fertilizers were added in large amounts we find either a decrease in the amount of water transpired or a very slight increase. The most marked increase found in this series is where nitrogen alone, and in a minimum quantity, was added. Both ten and twenty tons (per acre) of manure greatly decreased transpiration.

Table XII.—*Showing Total Green Weights and Percentage Increase or Decrease (—) in Green Weights Due to Fertilizers and Moisture.*

| Treatment. | 17.6 Percent W. | | 29.0 Percent W. | | 42.8 Percent W. | | Average Increase or Decrease in Green Wt. |
|---|---|---|---|---|---|---|---|
| | Gr. Wt. (Gms.). | Percent Increase or Decrease. | Gr. Wt. (Gms.). | Percent Increase or Decrease. | Gr. Wt. (Gms.). | Percent Increase or Decrease | |
| No treatment...... | 1.747 | X | 1.862 | X | 3.570 | X | X |
| 320 P............. | 1.365 | −21.9 | 2.050 | 10.1 | 3.335 | −6.6 | −6.13 |
| 80 K............. | 2.200 | 25.9 | 3.162 | 69.8 | 4.465 | 25.1 | 40.26 |
| 160 N............. | 2.650 | 51.7 | 3.930 | 111.1 | 4.740 | 32.8 | 65.20 |
| 320 P, 160 N...... | 2.342 | 34.0 | 3.510 | 88.5 | 4.483 | 25.6 | 49.36 |
| 320 P, 80 K...... | 2.050 | 17.3 | 2.365 | 27.0 | 3.720 | 4.0 | 16.10 |
| 160 N, 80 K...... | 3.045 | 74.3 | 3.250 | 74.5 | 5.270 | 47.6 | 65.46 |
| 320 P, 80 K, 160 N | 2.545 | 45.7 | 2.920 | 56.8 | 4.390 | 23.0 | 41.83 |
| 640 P, 80 K, 160 N | 2.155 | 23.4 | 3.380 | 81.5 | 4.435 | 24.2 | 43.03 |
| 640 P, 80 K, 320 N | 2.755 | 57.6 | 4.060 | 118.1 | 4.530 | 26.9 | 67.53 |
| 320 P, 80 K, 320 N | 2.825 | 61.7 | 3.687 | 98.0 | 6.105 | 71.0 | 76.90 |
| 320 P, 80 K, 640 N | 3.555 | 103.5 | 4.918 | 164.1 | 7.790 | 118.2 | 128.60 |
| 10 tons manure..... | 1.600 | 8.4 | 1.955 | 5.0 | 2.560 | −28.3 | −10.56 |
| 20 tons manure..... | 1.300 | −25.6 | 2.280 | 22.4 | 3.055 | −14.4 | − 5.86 |
| Average........... | 2.295 | 33.8 | 3.095 | 71.3 | 4.446 | 26.8 | 43.97 |

When the moisture content of the soil was increased from 17.6 percent to 29.0 percent, the fertilizers, rather than decreasing the amount of water transpired from the plants, produced an average increase of 9.76 percent for the entire series. Here the largest increases were obtained where the large applications of nitrogen were made. However, when the soil moisture was raised to 42.8 percent there is an average increase in transpiration for the entire series of only 2.93 percent, while the high nitrogen group gave the highest percentage increase in water transpired obtained in the entire test. The mineral fertilizers, when added alone or in combination, have tended to decrease transpiration.

The green weights of the plants, as shown in Table XII, bear very little relation to the amounts of water transpired. In the 17.6 percent moisture series, the fertilizers produced an average increase in green weight of crop of 33.8 percent; in the 29.0 percent moisture series an average increase of 71.3 percent was produced and in the 42.8 percent moisture series an increase of 26.8 percent was secured. The heavy applications of nitrogen were very effective in producing increased yields in green weight of crop.

In low moisture this increase was 103.5 percent; in medium moisture, 164.1 percent, and in high moisture 118.2 percent. We notice that where the moisture content of the soil was medium, all fertilizing materials, both singly and in combination, have increased the production of green material, whereas, in the low and high moisture soils alike, the single applications of acid phosphate and ten and twenty tons of manure have decreased the weight of green crop.

While the weight of green crop conforms more closely to the actual growth of the plants, as measured by dry matter produced, than does the transpiration, neither gives indications which are correct, as a study of the production of dry matter will show.

TABLE XIII.—*Showing Influence of Soil Moisture and Fertilizers Upon the Production of Dry Matter in Plants.*

| Treatment. | 17.6 Percent W. | | 29.0 Percent W. | | 42.8 Percent W. | | Average Increase or Decrease Percent. |
|---|---|---|---|---|---|---|---|
| | Dry Wt. (Gms.). | Percent Increase or Decrease. | Dry Wt. (Gms.). | Percent Increase or Decrease. | Dry Wt. (Gms.). | Percent Increase or Decrease. | |
| No treatment ...... | .5240 | X | .4596 | X | .8020 | X | X |
| 320 P............. | .4040 | −22.9 | .5332 | 16.0 | .7416 | − 7.5 | − 4.80 |
| 80 K............. | .5788 | 10.5 | .5504 | 19.8 | .8006 | − 0.17 | 10.03 |
| 160 N............. | .6630 | 26.5 | .8562 | 86.3 | .9580 | 19.5 | 44.10 |
| 320 P, 160 N...... | .5768 | 10.1 | .7570 | 64.7 | .9226 | 15.0 | 29.93 |
| 320 P, 80 K...... | .4556 | −13.1 | .5334 | 16.1 | .6886 | −14.1 | − 3.70 |
| 160 N, 80 K...... | .7810 | 49.0 | .6934 | 50.9 | .9624 | 20.0 | 39.96 |
| 320 P, 80 K, 160 N | .6312 | 20.5 | .6242 | 35.8 | .8460 | 5.5 | 20.60 |
| 640 P, 80 K, 160 N | .5226 | − 0.27 | .7340 | 59.7 | .8378 | 4.5 | 21.33 |
| 640 P, 80 K, 320 N | .6572 | 25.4 | .8426 | 83.4 | 1.0062 | 25.5 | 44.76 |
| 320 P, 80 K, 320 N | .6980 | 33.2 | .8394 | 82.6 | 1.0828 | 35.0 | 50.26 |
| 320 P, 80 K, 640 N | .8398 | 60.2 | 1.1446 | 127.1 | 1.5478 | 93.0 | 93.43 |
| 10 tons manure..... | .3878 | −26.0 | .4510 | −1.9 | .6712 | −16.3 | −14.73 |
| 20 tons manure..... | .3812 | −27.4 | .5660 | 23.1 | .6904 | −13.9 | − 6.05 |
| Average........... | .5858 | 11.2 | .6846 | 51.04 | .8970 | 13.7 | 25.01 |

The fertilizers have not shown exactly the same relations toward the moisture content of the soil when applied in the wire baskets as when applied to the pots. This, as has been previously mentioned, may be due in part to the much shorter period of growth in the baskets as compared with the pots. It will be remembered that with the pots the highest percentage increase due to fertilizers was obtained where the moisture content of the soil was quite low, 17.6 percent. This increase gradually became less following a rise in the soil moisture until at 42.8 percent moisture it had dropped from 124.28 percent in the beginnings to 32.08 percent.

Where the plants were grown for only three weeks, the fertilizers have reached their maximum efficiency in the medium moisture series, producing an average increase in dry matter of 51.04 percent. (See Fig. 22.) In the 42.8 percent moisture series an increase of 13.7 percent was produced, and in the 17.6 percent moisture an increase of 11.2 percent. In no case, either in the pot or basket tests, have the fertilizers attained their maximum efficiency in the 42.8 percent mois-

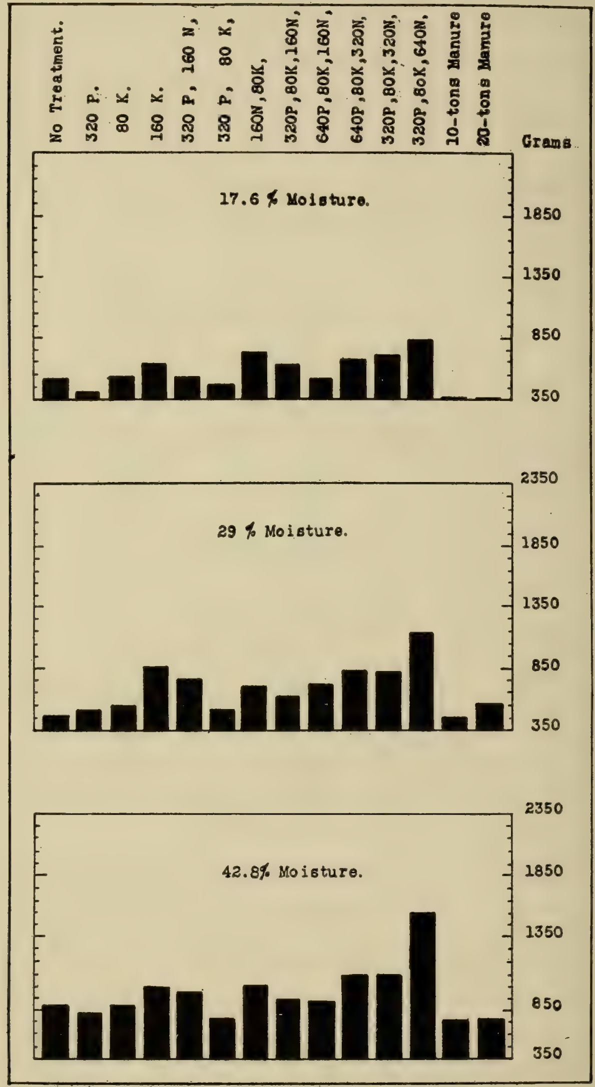

FIG. 22.—Production, in grams, of dry matter in plants (oats) grown in small wire baskets under varying conditions of soil moisture and fertilization.

ture series. In one case this has been reached in low soil moisture and in another in medium soil moisture. However, the pot test is the more reliable by far, as here the plants were grown practically to maturity. Where the plants grew to maturity the effects of the mineral fertilizers varied quite consistently with the moisture content of the soil, gradually decreasing in efficiency with the rise in moisture until an actual decreased yield was obtained in the high moisture.

Where the plants grew for only three weeks the mineral fertilizers affected the growth of plants very much alike in both low and high soil moisture, tending to decrease the yield, whereas in the medium moisture series, a beneficial effect was produced.

The nitrogen also gradually decreased in efficiency, as regards percentage increase, following an increase in soil moisture where the plants were grown to maturity.

The baskets, however, showed the most marked effects of nitrogen in the medium moisture series, followed next by high soil moisture and least in the low moisture. This applies to the high applications of nitrogen.

### *Effect of Fertilizers and the Moisture Content of the Soil Upon the Amount of Dry Matter Produced Per Gram of Transpiration.*

That the moisture content of the soil has influenced the amount of dry matter produced per gram of transpiration is quite evident from the fact that in the low moisture series the fertilizers decreased transpiration and increased the production of dry matter, whereas in the medium and high moisture the transpiration was increased.

TABLE XIV.—*Showing the Influence of Fertilizers and Soil Moisture Upon the Production of Dry Matter Per Gram of Transpiration (Grams).*

| Treatment. | Dry Matter per Gram of Transpiration (Grams). | | | |
|---|---|---|---|---|
| | 17.6 Percent W. | 29.0 Percent W. | 42.8 Percent W. | Average. |
| No treatment | .001136 | .000825 | .001123 | .001028 |
| 320 P | .001015 | .001040 | .001133 | .001062 |
| 80 K | .001283 | .000924 | .001190 | .001132 |
| 160 N | .001278 | .001233 | .001295 | .001268 |
| 320 P, 160 N | .001318 | .001135 | .001157 | .001203 |
| 320 P, 80 K | .001085 | .001108 | .001193 | .001128 |
| 160 N, 80 K | .001560 | .001034 | .001318 | .001304 |
| 320 P, 80 K, 160 N | .001377 | .001183 | .001201 | .001253 |
| 640 P, 80 K, 160 N | .001155 | .001261 | .001202 | .001206 |
| 640 P, 80 K, 320 N | .001412 | .001313 | .001273 | .001332 |
| 320 P, 80 K, 320 N | .001485 | .001344 | .001308 | .001379 |
| 320 P, 80 K, 640 N | .001782 | .001543 | .001617 | .001647 |
| 10 tons manure | .001064 | .001075 | .001089 | .001076 |
| 20 tons manure | .001084 | .001102 | .001087 | .001091 |
| Average | .001288 | .001151 | .001227 | |

It is quite evident from Table XIV, and also from Fig. 23, that both fertilizers and soil moisture have influenced the relation between transpiration and the production of dry matter. As regards the fertilizers, the nitrogen has had the most marked effect. Where the soil received a heavy application of sodium nitrate and therefore contained a solu-

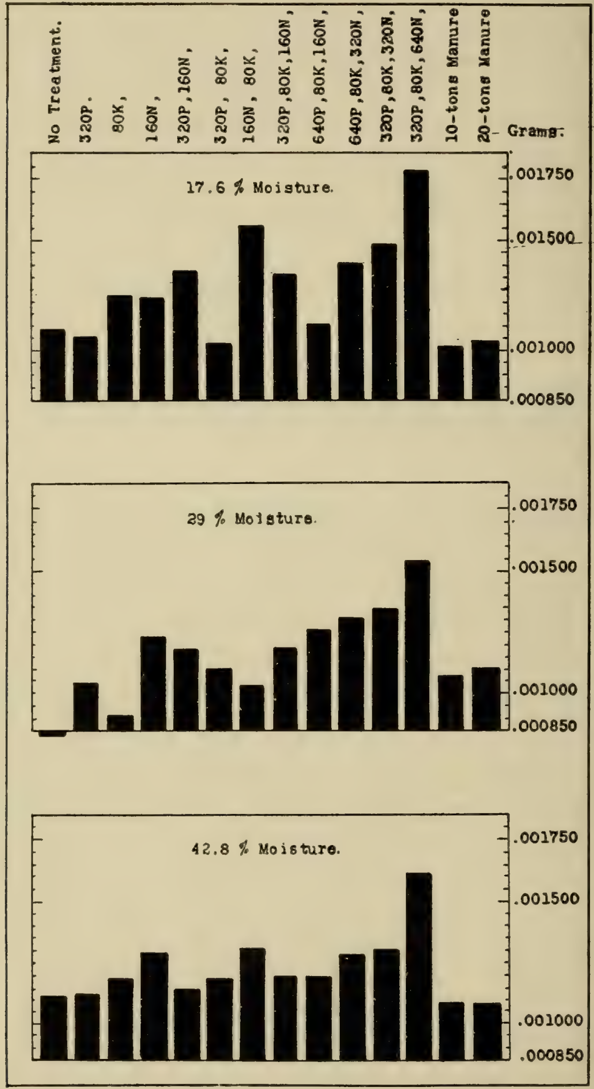

FIG. 23.—Amount of dry matter produced per gram of transpiration under varying conditions of soil moisture and fertilization (oats).

tion which was relatively high in nitrogen, there was a much greater amount of dry matter produced per gram of transpiration than where smaller amounts of nitrogen were present. In fact, this factor varied quite consistently with the amount of nitrogen present. If we consider the averages for the three series it will be seen that where even minimum amounts of nitrogen were added, there occurred an increase in dry matter per unit of water transpired. Increasing the nitrogen to 640 pounds nitrate per acre has increased the amount of dry matter per gram of transpiration, as indicated by the averages for the three series, from .001028 gram where no treatment was given to .001647 gram.

The mineral fertilizers have not produced a very marked influence upon the relation of dry matter to transpiration. This is quite likely due to the fact that the mineral elements of plant food are more readily absorbed by the soil than is the nitrogen, and hence are not so effective in varying the concentration of the soil solution.

The moisture content of the soil has also influenced the relation of transpiration to growth in a rather interesting manner. Where the soil moisture was very low and consequently the soil solution relatively concentrated, there has been a larger amount of dry matter produced per gram of transpiration than where the moisture content of the soil was medium. The peculiar thing is that when the soil moisture is still further increased to 42.8 percent and would naturally be considered quite dilute, the amount of dry matter per gram of transpiration again rises, though hardly so high as in the low moisture soil. This rise of dry matter in the high moisture series is quite consistent with nearly all fertilizer treatments and it seems unquestionably not a matter of chance.

### *Effect of Soil Moisture and Fertilizers Upon Root Development.*

The extent of root development was influenced to a greater extent by the moisture content of the soil than by the fertilizers. Where the soil moisture was quite low, the root growth was quite massive, very much more so than in the medium or high moisture soils. The roots were also more abundant in the medium moisture series than in the high moisture series.

With the exception of nitrogen, the fertilizers had very little effect upon root growth. High applications of nitrogen produced a very apparent increase in the growth of roots, especially in the low moisture series.

The roots from the various pots were not weighed, owing to the fineness and meager amount of development found in the high moisture series. However, the soil from every pot in all series was carefully worked over and notes taken as to the abundance and distribution of root growth. From these notes a table has been arranged showing as nearly as possible the relation of the different series and treatments, as regards root growth. These scores have been made upon the basis of 100 as the maximum development which was found in the low moisture series where 640 pounds (per acre) of nitrate of soda were added.

TABLE XV.—*Showing Relative Development of Plant Roots Under the Different Conditions of Soil Moisture and Fertilizers.*

100 = Maximum Development.

| Treatment. | 17.6 Percent W. | 29.0 Percent W. | 42.8 Percent W. | Average. |
|---|---|---|---|---|
| No treatment | 90 | 75 | 65 | 76.6 |
| 320 P | 88 | 75 | 65 | 76.0 |
| 80 K | 90 | 75 | 68 | 77.6 |
| 160 N | 90 | 75 | 65 | 76.6 |
| 320 P, 160 N | 92 | 75 | 65 | 77.3 |
| 320 P, 80 K | 90 | 75 | 62 | 75.6 |
| 160 N, 80 K | 90 | 75 | 65 | 76.6 |
| 320 P, 80 K, 160 N | 90 | 75 | 62 | 75.6 |
| 640 P, 80 K, 160 N | 90 | 75 | 65 | 76.6 |
| 640 P, 80 K, 320 N | 90 | 75 | 65 | 76.6 |
| 320 P, 80 K, 320 N | 95 | 75 | 67 | 79.0 |
| 320 P, 80 K, 640 N | 100 | 80 | 67 | 82.3 |
| 10 tons manure | 92 | 75 | 60 | 75.6 |
| 20 tons manure | 92 | 75 | 60 | 75.6 |
| Average | 91.3 | 75.3 | 64.3 | |

## *Soil Temperatures.*

Throughout the greater part of the growing period the following temperatures were taken at 8:30 A. M. and 4:30 P. M. daily.

Soil temperature 17.6 percent moisture, no treatment.
Soil temperature 17.6 percent moisture, manure (10 tons per acre).
Soil temperature 29.0 percent moisture, no treatment.
Soil temperature 29.0 percent moisture, manure (10 tons per acre).
Soil temperature 42.8 percent moisture, no treatment.
Soil temperature 42.8 percent moisture, manure (10 tons per acre).
Soil temperature 1.5 inches from side of pot.
Soil temperature 3.0 inches from side of pot.
Soil temperature 5.0 inches from side of pot.
Soil temperature 1.5 inches deep.
Soil temperature 3.0 inches deep.
Soil temperature 5.0 inches deep.
Air temperature, green house.
Temperature of water added.

All soil temperatures, unless otherwise stated, were taken at a depth of four inches from the surface of the soil. Regular soil thermometers were used in all pots except where the temperatures were obtained at different distances from the sides of the pots, and at different soil depths, in which cases regular chemical thermometers were used. Where temperatures were taken to determine the effects of soil moisture and treatments, care was taken to place the thermometers in the same relative position in all pots.

A chemical thermometer was also kept in the soil of one of the untreated wire baskets for each moisture series and readings from these were taken twice daily (8:30 A. M. and 4:30 P. M.) during the entire period of growth. The results are given in Table XVI.

Table XVI.—*Showing Average Temperatures (F.), by Months, of Soils in Different Moisture Series.*

| Date. | 17.6 Percent W. | | 29.0 Percent W. | | 42.8 Percent W. | | Temp. of Water Added. | Temperature of Greenhouse. | |
|---|---|---|---|---|---|---|---|---|---|
| | 8:30 A. M. | 4:30 P. M. | 8:30 A. M. | 4:30 P. M. | 8:30 A. M. | 4:30 P. M. | | 8:30 A. M. | 4:30 P. M. |
| Temperatures for Pot Series. | | | | | | | | | |
| Jan. | 54.2 | 57.6 | 55.4 | 57.3 | 55.9 | 58.2 | 50.8 | | |
| Feb. | 57.2 | 62.9 | 56.6 | 61.0 | 57.0 | 62.1 | 56.8 | 57.8 | 63.9 |
| Mar. | 58.1 | 65.4 | 57.8 | 65.2 | 58.5 | 65.0 | 56.4 | 61.7 | 65.1 |
| Average | 56.5 | 61.9 | 56.6 | 61.2 | 57.1 | 61.8 | 54.7 | 59.7 | 64.5 |
| Temperatures for Basket Series. | | | | | | | | | |
| Jan. | 59.8 | 64.3 | 59.5 | 63.5 | 57.4 | 60.1 | | | |
| Feb. | 61.7 | 67.2 | 60.8 | 66.0 | 58.7 | 65.8 | | | |
| Average | 60.7 | 65.7 | 60.1 | 64.7 | 58.0 | 62.9 | | | |

The greenhouse temperatures were taken by placing a thermometer between the pots so as to show exactly the temperature conditions of the air immediately in contact with the pots and soil. The temperature of the greenhouse in general was a few degrees higher than that indicated in the tables, as is evident from the fact that the soil in the wire baskets shows a temperature somewhat higher than that of the air immediately surrounding the pots. The baskets were placed upon shelves which were quite a bit higher than those upon which the pots sat, and this accounts for the higher temperature of the air in the vicinity of the baskets.

It is a rather interesting fact that, in the case of the pots, the temperature of the soil increased with the increase in soil moisture. As the specific heat of water is much greater than that of the soil, the opposite condition would be expected. However, the explanation of this higher temperature in the soil containing high moisture is undoubtedly the fact that, owing to the increased amount of moisture in the soil, the particles ran together in a more compact mass, the soil air was more thoroughly excluded and hence the conductivity of the soil for heat was increased. That the soil in the low moisture series occupied a greater volume than that in the high moisture series is certain, the low moisture soil having a volume weight of .0354, that of the high moisture series .0438, while the porosity of the low moisture soil was 63.93 and that of the high moisture 55.19. Air is a much poorer conductor of heat than either soil or water, and as the soil with low moisture was less compact and contained more air than that with the high moisture, it is natural to believe that it would be a poorer conductor of heat.

That the heat entered the soil by means of conductivity is shown by the data in Table XVII.

Table XVII.—*Showing Average Temperature of Soil at Different Distances from Sides of Pot and at Different Depths.*

| Date. | 1.5 Inch from Side of Pot. | | 3 Inches from Side of Pot. | | 5 Inches from Side of Pot. | | 1.5 Inch Deep. | | 3 Inches Deep. | | 5 Inches Deep. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 8:30 A. M. | 4:30 P. M. | 8:30 A. M. | 4:30 P. M. | 8:30 A. M. | 4:30 P. M. | 8:30 A. M. | 4:30 P. M. | 8:30 A. M. | 4:30 P. M. | 8:30 A. M. | 4:30 P. M. |
| Feb. | 56.6 | 65.6 | 55.8 | 65.2 | 55.6 | 65.0 | 56.6 | 64.9 | 56.1 | 65.0 | 55.9 | 64.9 |
| Mar. | 61.6 | 67.9 | 60.8 | 67.2 | 60.5 | 67.4 | 61.6 | 67.1 | 60.8 | 67.0 | 60.8 | 67.00 |
| Aver. | 59.10 | 66.75 | 58.30 | 66.20 | 58.05 | 66.20 | 59.10 | 66.00 | 58.45 | 66.00 | 58.35 | 65.90 |

It will be seen that as the distance from the side of the pot or the depth increased, the temperature gradually decreased. This was not so marked in the afternoon temperatures as in the case of those taken in the early morning, due to the fact that by 4:30 P. M. the atmosphere in the greenhouse was getting cooler and hence the surface of the soil had begun to radiate heat.

The soil in the wire baskets decreased in temperature following an increase in soil moisture. This is easily explained from the fact that the soil was thoroughly compacted as the baskets were filled and hence there was no marked "running together" of the soil particles here as there was in the case of the pots where the soil was more open. Under these conditions, it is probable that the temperature of the soil would be influenced more by the relative specific heats of soil and water than by conductivity.

Temperatures were also taken to determine the effect of the application of stable manure to the soil upon its temperature.

Table XVIII gives the results:

TABLE XVIII.—*Showing the Effect of Stable Manure Upon the Temperature of the Soil.*

| Date. | 17.6 Percent Moisture. | | | | 29.0 Percent Moisture. | | | | 42.8 Percent Moisture. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No Treat. | | 10 Tons Manure. | | No Treat. | | 10 Tons Manure. | | No Treat. | | 10 Tons Manure. | |
| | 8:30 A. M. | 4:30 P. M. | 8:30 A. M. | 4:30 P. M. | 8:30 A. M. | 4:30 P. M. | 8:30 A. M. | 4:30 P. M. | 8:30 A. M. | 4:30 P. M. | 8:30 A. M. | 4:30 P. M. |
| Feb. | 55.5 | 65.7 | 55.6 | 66.5 | 55.6 | 65.6 | 57.0 | 66.8 | 56.8 | 66.9 | 56.1 | 67.1 |
| Mar. | 60.1 | 66.9 | 60.9 | 67.3 | 60.4 | 67.1 | 61.4 | 67.5 | 60.6 | 67.1 | 61.1 | 67.3 |
| Aver. | 57.8 | 66.3 | 58.2 | 66.9 | 58.0 | 66.3 | 59.2 | 67.1 | 58.7 | 67.0 | 58.6 | 67.2 |

In both the low and medium moisture soils the stable manure has produced an apparent increase in the soil temperature, while in the high moisture series there was no marked effect. The manure has not, however, produced a very marked increase in yield. How much of this increased yield was the result of the higher temperatures in the manured pots and how much was due to the other effects of the manure, of course, is not known.

### *Effect of Soil Moisture and Fertilizers Upon the Total and Albuminoid Nitrogen in Crop.*

It is a fact quite commonly observed that some plants when grown under varying climatic conditions, show also marked variations as regards their chemical constitution. In order to determine to what extent the nitrogen content of the oat plant is affected by such factors as the moisture content of the soil and the amount and nature of the fertilizing elements present in the soil, the following determinations have been made upon the plants grown under the different conditions as regards soil moisture and fertilizers:

1. Percent total nitrogen in crop.
2. Grams total nitrogen in crop.
3. Percent albuminoid nitrogen in crop.
4. Grams albuminoid nitrogen in crop.

The results of the above determinations are for the total above ground parts of the plants harvested when the grain was in the milk stage.

Table XIX gives the percentage total nitrogen in plants. See also Fig. 24.

TABLE XIX.—*Showing Influence of Soil Moisture and Fertilizers Upon Percentage Total Nitrogen in Crop (Dry Matter).*

| Treatment. | Percent Total Nitrogen. | | | |
|---|---|---|---|---|
| | 17.6 Percent W. | 29.0 Percent W. | 42.8 Percent W. | Average. |
| No treatment | 1.09 | 1.21 | 1.07 | 1.123 |
| 320 P | .97 | 1.24 | 1.20 | 1.136 |
| 80 K | 1.06 | 1.21 | 1.18 | 1.150 |
| 160 N | 1.10 | .94 | 1.05 | 1.030 |
| 320 P, 160 N | .91 | .86 | .98 | .916 |
| 320 P, 80 K | 1.03 | 1.14 | 1.17 | 1.113 |
| 160 N, 80 K | 1.14 | .94 | 1.00 | 1.026 |
| 320 P, 80 K, 160 N | .83 | .93 | .94 | .900 |
| 640 P, 80 K, 160 N | .84 | .90 | .97 | .903 |
| 640 P, 80 K, 320 N | .97 | .92 | .98 | .956 |
| 320 P, 80 K, 320 N | .91 | .93 | .91 | .916 |
| 320 P, 80 K, 640 N | 1.29 | .92 | .88 | 1.030 |
| 10 tons manure | .93 | 1.12 | 1.09 | 1.046 |
| 20 tons manure | .88 | 1.20 | 1.24 | 1.106 |
| Average | .99 | 1.03 | 1.04 | |

The averages for the three different moisture series show a slight increase in the percentage total nitrogen in crop, following an increase in the soil moisture. However, it will be noticed that the effect of the soil moisture upon the nitrogen content of the crop is influenced, to a marked extent, by the nature of the fertilizer added. Where mineral fertilizers were used alone or where large amounts were combined with small amounts of nitrogen, the tendency has been to produce a higher percentage of nitrogen content in crop following an increase in soil moisture. Where a nitrogen fertilizer was added either alone or as the predominating constituent of a mixed fertilizer, the nitrogen content of crop decreased following an increase in the moisture content of the soil. These results agree, to a certain extent, with some results obtained by Von Seelhorst in Germany, in which he found that where mineral fertilizers were added the moisture content of the soil produced little effect upon the percent nitrogen in crop, but where nitrogenous fertilizers were added, an increase in soil moisture was accompanied by a decrease in the percent nitrogen in crop.

Large amounts of phosphoric acid have tended to decrease the percent nitrogen in crop. Nitrogen, when added in large amounts, greatly increased the percent nitrogen in the crop grown upon the low moisture series, but this rapidly decreased as the soil moisture was increased. The effect of potash could not be so well studied as it was added in only one quantity, and this rather small. However, the tendency seems to have been for the potash to slightly increase the percent nitrogen in crop.

The most interesting effect produced by the fertilizers is the very marked influence which the 640 pounds (per acre) of nitrate of soda has had upon the nitrogen content of plants where the soil moisture was quite low. The plants grown under these conditions contained 1.29 percent nitrogen as compared with an average for the series of .99 percent. Where the moisture content was medium and high the crop produced was below the average in percentage nitrogen. This

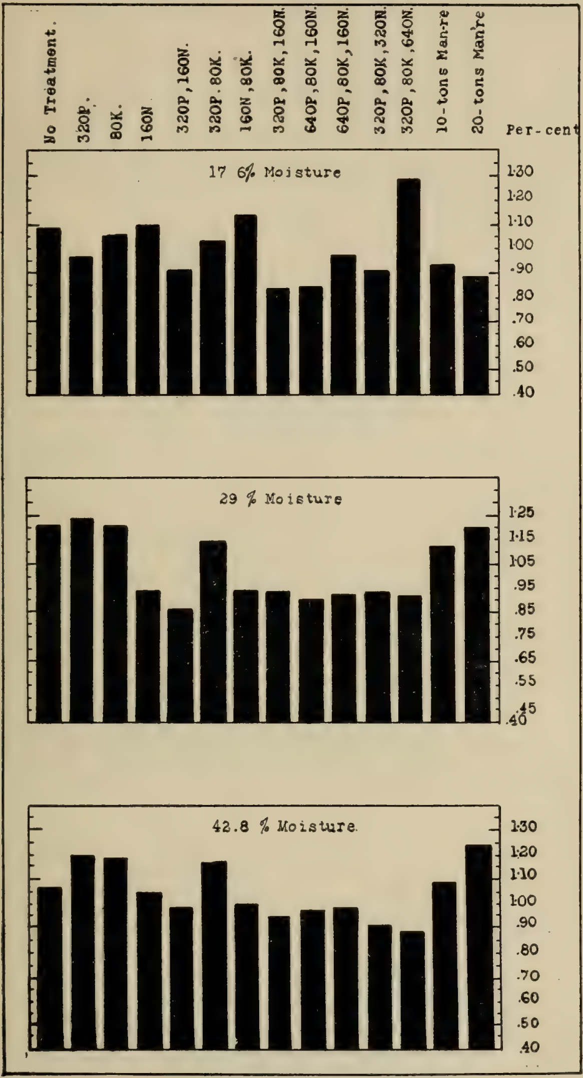

FIG. 24.—Percent of total nitrogen in crop (oats) grown under varying conditions of soil moisture and fertilization.

would seem to indicate a more concentrated soil solution where the soil moisture was low.

There is also a close relation between the yield of crop and the percentage nitrogen which it contains. This will be shown in Table XX.

TABLE XX.—*Showing the Influence of Yield Upon the Percentage Total Nitrogen in Dry Matter.*

| Yield in Grams of Dry Matter. | Average Percent Total N. | | | | |
|---|---|---|---|---|---|
| | 17.6 Percent W. | 29.0 Percent W. | 33.3 Percent W. | 42.8 Percent W. | Average. |
| 0–10 | 1.016 | | 1.103 | | 1.059 |
| 10–20 | 0.950 | 1.123 | 0.868 | 1.116 | 1.014 |
| 20–30 | 1.056 | 0.905 | 0.820 | 0.970 | .938 |
| 30–40 | | 0.925 | | 0.880 | .902 |

In the above table an attempt has been made to classify the yields in such a way as to show the relation between the production of dry matter and the percentage total nitrogen in the crop. For example, all yields under ten grams came in class 1, all yields over ten and under twenty grams in class 2, etc., and the average percentage nitrogen for the different soil moistures is given for each class.

It is quite evident, as the column of averages for the different soil moistures will show, that there is quite a close relation between the yield of dry matter and the percentage total nitrogen in the crop. As the production of dry matter increases, the percentage nitrogen decreases.

### *Grams Total Nitrogen Produced.*

Table XXI shows the influence of the soil moisture and fertilizers upon the grams of total nitrogen produced. See also Fig. 25.

TABLE XXI.—*Showing Influence of Soil Moisture and Fertilizers Upon Grams Total Nitrogen in Crop.*

| Treatment. | 17.6 Percent W. | 29.0 Percent W. | 42.8 Percent W. | Average. |
|---|---|---|---|---|
| No treatment | .0697 | .1411 | .1663 | .1257 |
| 320 P | .0875 | .1411 | .1797 | .1361 |
| 80 K | .0754 | .1502 | .1952 | .1403 |
| 160 N | .1251 | .1893 | .2171 | .1772 |
| 320 P, 160 N | .1370 | .1959 | .2175 | .1835 |
| 320 P, 80 K | .0902 | .1402 | .1604 | .1303 |
| 160 N, 80 K | .1440 | .1719 | .1987 | .1715 |
| 320 P, 80 K, 160 N | .1290 | .1550 | .1967 | .1602 |
| 640 P, 80 K, 160 N | .1339 | .1828 | .2170 | .1779 |
| 640 P, 80 K, 320 N | .2109 | .1901 | .1934 | .1981 |
| 320 P, 80 K, 320 N | .1944 | .2820 | .1984 | .2249 |
| 320 P, 80 K, 640 N | .3606 | .3474 | .3555 | .3545 |
| 10 tons manure | .0788 | .1594 | .1965 | .1449 |
| 20 tons measure | .0921 | .1412 | .2094 | .1476 |
| Average | .1377 | .2049 | .2072 | |

The amount, in grams, of total nitrogen produced, increased as the moisture content of the soil increased. This was quite marked following an increase in moisture from 17.6 percent to 29.0 percent.

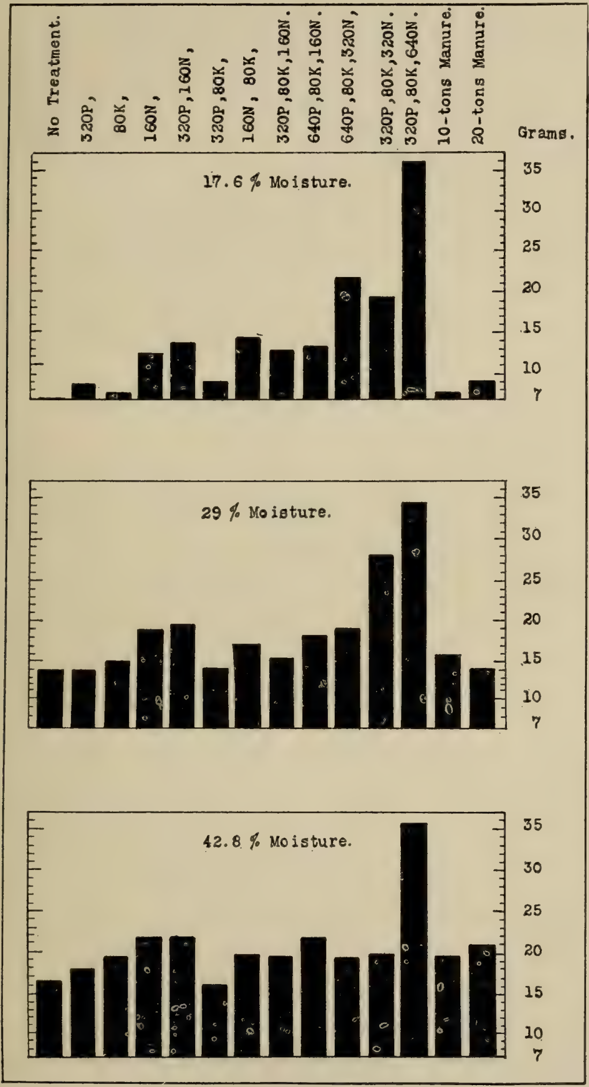

FIG. 25.—Production, in grams, of total nitrogen in crop (oats) under varying conditions of soil moisture and fertilization.

Beyond this point there was, in general, a very slight increase. It will be remembered that the yield of dry substance also increased following a rise in soil moisture, particularly from low to medium moisture, and this largely accounts for the increased production of nitrogen. However, one or two very interesting exceptions occur. Where nitrate of soda was added at the rate of 640 pounds per acre, there was produced, in the crop from the low moisture soil, a total weight of nitrogen greater than that produced in the crops from either the medium or high moisture soils. This is the more interesting when we notice that the production of dry matter was very much less upon the dry than upon the medium or high moisture soils, amounting to a difference of almost 70 percent between the low and high moisture series. This, of course, was due to the exceptionally high percentage of nitrogen in the crop from the dry soil.

### *Effect of Soil Moisture and Fertilizers Upon the Percentage Albuminoid Nitrogen in Crop.*

In Table XXII is given the percentage of albuminoid nitrogen in crop:

Table XXII.—*Showing Influence of Soil Moisture and Fertilizers Upon the Percentage Albuminoid Nitrogen in Crop (Dry Matter).*

| Treatment. | Percent Albuminoid Nitrogen. | | | |
|---|---|---|---|---|
| | 17.6 Percent W. | 29.0 Percent W. | 42.8 Percent W. | Average. |
| No treatment | .72 | .83 | .70 | .750 |
| 320 P | .86 | .81 | .76 | .810 |
| 80 K | .75 | .90 | .79 | .813 |
| 160 N | .72 | .67 | .64 | .676 |
| 320 P, 160 N | .68 | .59 | .74 | .670 |
| 320 P, 80 K | .73 | .78 | .80 | .770 |
| 160 N, 80 K | .78 | .62 | .67 | .690 |
| 320 P, 80 K, 160 N | .60 | .63 | .63 | .620 |
| 640 P, 80 K, 160 N | .55 | .63 | .67 | .616 |
| 640 P, 80 K, 320 N | .53 | .59 | .74 | .620 |
| 320 P, 80 K, 320 N | .58 | .55 | .58 | .570 |
| 320 P, 80 K, 640 N | .84 | .50 | .50 | .613 |
| 10 tons manure | .67 | .67 | .71 | .683 |
| 20 tons manure | .67 | .64 | .80 | .704 |
| Average | .69 | .67 | .69 | |

The percentage albuminoid nitrogen in crop shows in a general way, the same relations toward the soil moisture and fertilizers as did the total nitrogen. Where mineral fertilizers were added in large quantities, there is a tendency for the percentage of albuminoid nitrogen in the crop to increase following an increase in soil moisture. Where the amounts of nitrogen in the soil were relatively high the percentage albuminoid nitrogen in crop decreased as the moisture content of the soil increased.

The crop showing the highest percentage of albuminoid nitrogen was that grown upon the dry soil to which 640 pounds nitrate of soda (per acre) had been added. However, when the moisture content of the soil was raised from 17.6 percent to 29.0 percent the percentage albuminoid nitrogen dropped from .84 percent to .50 percent. The high moisture soil with this same fertilizer also produced a crop with .50 percent albuminoid nitrogen.

Table XXIII shows the production, in grams, of albuminoid nitrogen for the crops grown under the different conditions:

TABLE XXIII.—*Showing Influence of Soil Moisture and Fertilizers Upon Grams Albuminoid Nitrogen in Crop.*

| Treatment. | Grams Albuminoid Nitrogen. | | | |
|---|---|---|---|---|
| | 17.6 Percent W. | 29.0 Percent W. | 42.8 Percent W. | Average. |
| No treatment | .0456 | .0972 | .1091 | .0839 |
| 320 P | .0766 | .0962 | .1135 | .0954 |
| 80 K | .0533 | .1112 | .1306 | .0984 |
| 160 N | .0817 | .1348 | .1325 | .1163 |
| 320 P, 160 N | .1014 | .1335 | .1634 | .1328 |
| 320 P, 80 K | .0639 | .0957 | .1100 | .0899 |
| 160 N, 80 K | .0986 | .1129 | .1332 | .1149 |
| 320 P, 80 K, 160 N | .0925 | .1049 | .1317 | .1097 |
| 640 P, 80 K, 160 N | .0876 | .1281 | .1492 | .1216 |
| 640 P, 80 K, 320 N | .1149 | .1223 | .1459 | .1277 |
| 320 P, 80 K, 320 N | .1231 | .1670 | .1250 | .1387 |
| 320 P, 80 K, 640 N | .2349 | .1883 | .2012 | .2081 |
| 10 tons manure | .0562 | .0955 | .1283 | .0933 |
| 20 tons manure | .0695 | .0753 | .1354 | .0934 |
| Average | .0928 | .1188 | .1363 | |

The total production of albuminoid nitrogen is influenced by soil moisture and fertilizers in the same general way as was the total nitrogen. An increase in soil moisture increased the amount of albuminoid nitrogen chiefly by increasing the yield of crops. Where the maximum amount of nitrogen was added there was a greater amount of albuminoid nitrogen produced in the crop from the low than from the high moisture soil.

The percentage albuminoid nitrogen in total nitrogen averaged slightly higher in the crop grown upon the soil with low moisture than in the crops grown upon the medium and high moisture soils. There seems to be no definite relation between the fertilizer treatments and the amount of albuminoid nitrogen in total nitrogen, except that, generally speaking, where mineral fertilizers were added alone or in large amounts, this percentage is greater in the crop from the high moisture series than from the low, and where nitrogen predominates, the reverse is true. Where the maximum amount of nitrogen was added, there occurred the smallest average percentage of albuminoid nitrogen in total nitrogen.

TABLE XXIV.—*Showing Percentage Albuminoid Nitrogen in Total Nitrogen. Also Maximum Variation in Percent Albuminoid Nitrogen in Total Nitrogen.*

| Treatment. | Album. N in Total N; Percent. | | | |
|---|---|---|---|---|
| | 17.6 Percent W. | 29.0 Percent W. | 42.8 Percent W. | Average. |
| No treatment | 65.43 | 68.88 | 65.60 | 66.64 |
| 320 P | 87.45 | 68.17 | 63.16 | 72.93 |
| 80 K | 70.69 | 74.11 | 66.90 | 70.56 |
| 160 N | 65.31 | 71.28 | 61.10 | 65.89 |
| 320 P, 160 N | 74.02 | 68.12 | 75.22 | 72.45 |
| 320 P, 80 K | 70.84 | 68.25 | 68.58 | 69.22 |
| 160 N, 80 K | 68.47 | 65.75 | 67.05 | 67.09 |
| 320 P, 80 K, 160 N | 71.71 | 67.75 | 67.03 | 68.83 |
| 640 P, 80 K, 160 N | 65.49 | 70.08 | 68.84 | 68.14 |
| 640 P, 80 K, 320 N | 54.48 | 64.40 | 75.52 | 64.80 |
| 320 P, 80 K, 320 N | 63.38 | 59.22 | 63.00 | 61.87 |
| 320 P, 80 K, 640 N | 65.15 | 54.26 | 56.60 | 58.67 |
| 10 tons manure | 71.32 | 59.90 | 65.30 | 65.51 |
| 20 tons manure | 75.46 | 53.32 | 64.66 | 64.48 |
| Average | 69.23 | 65.25 | 66.32 | |
| Maximum variation | 32.97 | 20.79 | 18.92 | |

There is also a much wider range of variation in the percent albuminoid nitrogen in total nitrogen, in the low moisture series than in the crop from the medium and high moisture series, this variability decreasing as the moisture content of the soil increases.

So far, the total and albuminoid nitrogen in the crop from the series with a soil moisture of 33.3 percent has not been considered. Table XXV gives the data for this series:

There is in the above series, quite a close relation between the production of dry matter and the percent total and albuminoid nitrogen in the crop, these being highest where the amount of dry matter produced is lowest.

It would appear that nitrogen, when added in low or medium amounts does not materially affect the composition of the crop as regards percentage nitrogen, but when added in rather large amounts its effect upon the nitrogen content of crop is very marked, especially if the moisture content of the soil is low.

It has been previously pointed out that the percentage nitrogen in the crop quite consistently decreases as the yield of dry matter increases. However, it must be remembered that this does not hold true where the increase in dry matter has been produced as the result of a heavy application of nitrogen to a relatively dry soil.

TABLE XXV.—*Showing Production of Dry Matter, Percent Total Nitrogen, Grams Total Nitrogen, Percent Albuminoid Nitrogen and Grams Albuminoid Nitrogen in Crop from 33.3 Percent Soil Moisture Series.*

| Treatment. | Soil Moisture 33.3 Percent. | | | | |
|---|---|---|---|---|---|
| | Dry Matter. | Percent Total Nitrogen. | Grams Total Nitrogen. | Percent Albuminoid Nitrogen. | Grams Albuminoid Nitrogen. |
| No treatment | 11.791 | .93 | .1097 | .72 | .0848 |
| 320 P | 8.562 | 1.11 | .0956 | .76 | .0651 |
| 80 K | 9.469 | .97 | .0921 | .70 | .0662 |
| 160 N | 15.910 | .88 | .1398 | .58 | .0923 |
| 320 P, 160 N | 15.538 | .87 | .1352 | .64 | .0994 |
| 320 P, 80 K | 7.756 | 1.23 | .0959 | .80 | .0625 |
| 160 N, 80 K | 19.978 | .86 | .1729 | .60 | .1199 |
| 320 P, 80 K, 160 N | 16.189 | .88 | .1423 | .64 | .1036 |
| 640 P, 80 K, 160 N | 17.319 | .79 | .1377 | .54 | .0935 |
| 640 P, 80 K, 320 N | 23.118 | .83 | .1925 | .55 | .1271 |
| 320 P, 80 K, 320 N | 26.011 | .81 | .2114 | .54 | .1405 |
| 10 tons manure | 15.802 | .84 | .1327 | .63 | .0995 |
| 20 tons manure | 15.849 | .97 | .1538 | .71 | .1125 |
| Average | 15.637 | .92 | .1393 | .64 | .0974 |

## PART II.

During the winter of 1908–9, the work, though somewhat modified, was of the same general nature as that conducted the preceding year. In this latter work it was desired to ascertain the effect, under different conditions of soil moisture, produced upon the yield and composition of the crop by fertilizing at different stages in the life of the plant.

The soil used in this test was from the same plat as that used in the test of 1907–8. The same sized pots were used but the amount of soil per pot was increased from 7.5 to 10.5 kilograms. Wheat, rather than oats, was grown.

Two soil moisture contents were maintained, one series containing a low soil moisture of 17.6 percent and another a high moisture content of 42.8 percent, figured upon the basis of water-free soil.

The life of the plants was divided into four stages as follows:
1st stage: from planting to five well-developed leaves.
2d stage: from end of first stage to indications of spike in culm.
3d stage: from end of second stage to beginning of blooming.
4th stage: from end of third stage to maturity.

The combinations of fertilizers used were, (1) a complete fertilizer and (2) a high nitrogen fertilizer. These were added at the following rates per acre.

Complete fertilizer
- Nitrate of soda 300 lbs.
- Muriate of potash 100 lbs.
- Acid phosphate 300 lbs.

High nitrogen fertilizer
- Nitrate of soda 1000 lbs.
- Muriate of potash 100 lbs.
- Acid phosphate 300 lbs.

Table XXVI gives the plan of the experiment:

TABLE XXVI.—*Showing Moisture Content of Soil, Fertilizer Treatments and Stages at Which Plants were Harvested for Analysis.*

| | | Fertilizing at Different Stages. | | | |
|---|---|---|---|---|---|
| Pot No. | Soil Moisture. | 1st Stage. | 2d Stage. | 3d Stage. | Time of Harvesting. |
| 81 and 82 | 17.6 | Comp. Fert. | Comp. Fert. | Comp. Fert. | Maturity |
| 83 and 84 | 17.6 | No Fert. | Comp. Fert. | Comp. Fert. | Maturity |
| 85 and 86 | 17.6 | No Fert. | No Fert. | Comp. Fert. | Maturity |
| 87 and 88 | 17.6 | No Fert. | No Fert. | No Fert. | Maturity |
| 89 and 90 | 17.6 | High N Fert. | High N Fert. | High N Fert. | Maturity |
| 91 and 92 | 17.6 | No Fert. | High N Fert. | High N Fert. | Maturity |
| 93 and 94 | 17.6 | No Fert. | No Fert. | High N Fert. | Maturity |
| 95 and 96 | 42.8 | Comp. Fert. | Comp. Fert. | Comp. Fert. | Maturity |
| 97 and 98 | 42.8 | No Fert. | Comp. Fert. | Comp. Fert. | Maturity |
| 99 and 100 | 42.8 | No Fert. | No Fert. | Comp. Fert. | Maturity |
| 101 and 102 | 42.8 | No Fert. | No Fert. | No Fert. | Maturity |
| 103 and 104 | 42.8 | High N Fert. | Nigh H Fert. | High N Fert. | Maturity |
| 105 and 106 | 42.8 | No Fert. | High N Fert. | High N Fert. | Maturity |
| 107 and 108 | 42.8 | No Fert. | No Fert. | High N Fert. | Maturity |
| 109 and 110 | 17.6 | Comp. Fert. | | | End 1st stage |
| 111 and 112 | 17.6 | No Fert. | | | End 1st stage |
| 113 and 114 | 17.6 | Comp. Fert. | Comp. Fert. | | End 2d stage |
| 115 and 116 | 17.6 | No Fert. | Comp. Fert. | | End 2d stage |
| 117 and 118 | 17.6 | No Fert. | No Fert. | | End 2d stage |
| 119 and 120 | 17.6 | Comp. Fert. | Comp. Fert. | Comp. Fert. | End 3d stage |
| 121 and 122 | 17.6 | No Fert. | Comp. Fert. | Comp. Fert. | End 3d stage |
| 123 and 124 | 17.6 | No Fert. | No Fert. | Comp. Fert. | End 3d stage |
| 125 and 126 | 17.6 | No Fert. | No Fert. | No Fert. | End 3d stage |

On October 7 complete fertilizers were added to the soil in pots 81 and 82, 95 and 96, 109 and 110, and in 113 and 114; high nitrogen fertilizers were added to pots 89 and 90 and to 103 and 104. The fertilizers were thoroughly incorporated with the top three inches of soil.

On October 16 pots 81–118 were planted to wheat the variety used being a spring wheat known as Galgalos. Pots 119–126 were not added to the series until later and hence were not planted until November 27.

The plants germinated well and grew off nicely, and on November 2 the plants in all pots 81–118 were thinned to twelve plants per pot.

On December 28 the plants in all pots from 81–118 contained five well-developed leaves and this was taken as the end of stage 1. Consequently on this date, according to the plan of the experiment, complete fertilizers were added to the soil in pots 83 and 84, 97 and 98 and 115 and 116, and high nitrogen fertilizers were added to pots 91 and 92 and to 105 and 106. This was done by removing the quartz mulch from the surface of the soil and carefully stirring the soil to the depth of one inch. The fertilizers were then added and stirred into the soil, when the quartz was replaced. Care was taken not to injure any of the plants.

Also upon the above date, plants in pots 109–112 were harvested for yield and analysis. Another crop was planted in the same pots so as to be sure to have enough material for analysis.

In a very few days after the fertilizers were added, a difference could be noticed in the growth and color of the plants, especially where the high nitrogen fertilizers were added.

On March 1 the second crop of plants in pots 109–112 had reached the end of the first stage and were harvested as before. Complete fertilizers were again added to pots 109 and 110 and all four pots planted for another crop of wheat.

On March 8, indications of the spike were present in almost all of the culms of plants growing in pots 81–118, this being true of plants growing in both high and low soil moisture. This period was regarded at the end of stage 2, and complete fertilizers were added to pots 85 and 86, 99 and 100. High nitrogen fertilizers were added to pots 93 and 94, 107 and 108. The plants in pots 113–118 were harvested for yield and analysis. No further applications of fertilizers were made to any of the plants in this series (81–118). The plants in pots 81–108 were grown to maturity.

Table XXVII shows the influence of the soil moisture and fertilizers upon the stooling of the plants. See also Fig. 26.

TABLE XXVII.—*Showing Influence of Soil Moisture and Fertilizers Upon Stooling of Plants.*

| Treatment. | 17.6 Percent W. | | 42.8 Percent W. | | Average Percent. |
|---|---|---|---|---|---|
| | No. Stooling. | Percent. | No. Stooling. | Percent. | |
| Comp. fert. 1st stage.... | 4 | 16.66 | 22 | 91.66 | 54.16 |
| Comp. fert. 2d stage.... | 1 | 4.17 | 19 | 79.17 | 41.67 |
| Comp. fert. 3d stage.... | 0 | 0.00 | 19 | 79.17 | 39.58 |
| No fertilizer........... | 0 | 0.00 | 20 | 83.33 | 41.66 |
| High N fert. 1st stage... | 18 | 75.00 | 24 | 100.00 | 87.50 |
| High N fert. 2d stage... | 2 | 8.33 | 22 | 91.66 | 49.99 |
| High N fert. 3d stage... | 0 | 00.00 | 23 | 95.83 | 47.91 |
| Average............... | 3.57 | 14.87 | 21.28 | 88.66 | |

An increase in soil moisture has greatly increased the stooling of the wheat plants. It will be remembered that with the oats the opposite effect was produced. Why the moisture content of the soil should influence the stooling of the wheat plants differently from that of the oats is difficult to say unless it is in some way due to the individuality of the two species as regards their moisture relations. It would be expected that an increase in soil moisture, other things being equal, would increase the stooling of both oats and wheat.

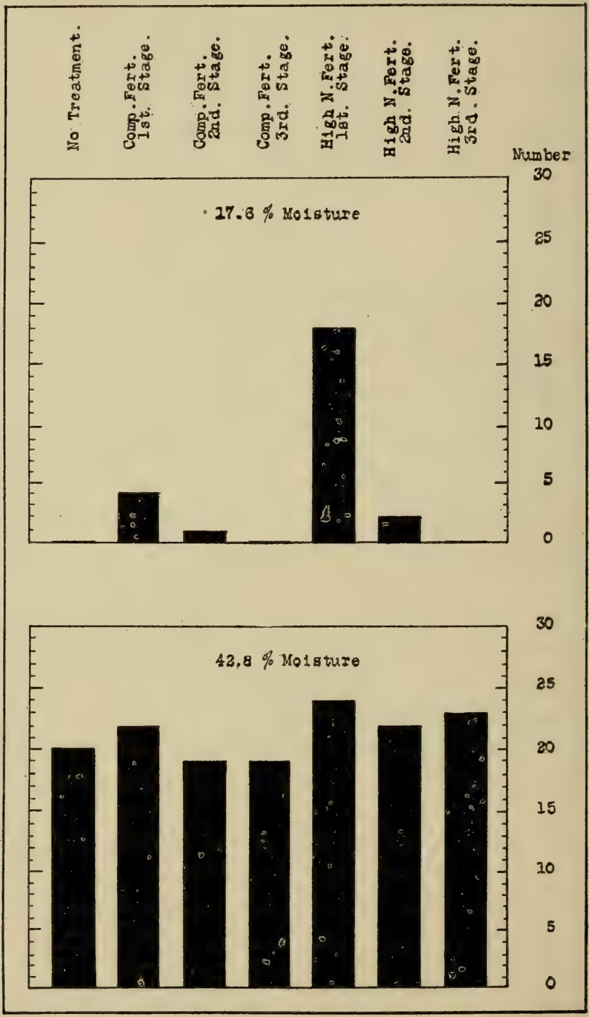

FIG. 26.—Number of plants (wheat) stooling under the different conditions of soil moisture and fertilization.

The fertilizers have also greatly influenced the stooling of the wheat plants. This is more marked with the high nitrogen than with the complete fertilizer and in both cases is greatest where the fertilizers were applied at the beginning of the first stage, decreasing as the length of the period from planting to fertilizing increases. In the high moisture series, where the high nitrogen fertilizer was applied at the beginning of the first stage, 100 percent of the plants stooled.

In the low moisture series, very few of the secondary plants, or stools, grew to maturity, nearly all of them dying within three weeks after they first appeared. Where the high soil moisture was maintained, a very much greater proportion of the stools grew to maturity. It was also noticed that when the high nitrogen fertilizers were applied to the plants in the high moisture series at as late a date as the beginning of the third stage, there were a number of shoots thrown out, though they never grew enough to amount to anything.

Table XXVIII shows the influence of the soil moisture and fertilizers upon the number of days from planting to heading:

TABLE XXVIII.—*Showing Number of Days from Planting to Heading.**

| Treatment. | 17.6 Percent W. | 42.8 Percent W. | Average. |
|---|---|---|---|
| Comp. fert. 1st stage | 173.5 | 172.5 | 173.0 |
| Comp. fert. 2d stage | 170.5 | 173.5 | 172.0 |
| Comp. fert. 3d stage | 176.5 | 177.0 | 176.7 |
| No fertilizer | 178.5 | 177.0 | 177.5 |
| High N fert. 1st stage | 163.5 | 174.0 | 168.7 |
| High N fert. 2d stage | 168.0 | 175.0 | 171.5 |
| High N fert. 3d stage | 177.0 | 179.0 | 178.0 |
| Average | 172.5 | 175.4 | |

It will be seen that the increase in soil moisture has increased the length of time from planting to heading practically three days. It is also a very noticeable fact that where the complete fertilizer was added at either the first, second or third stage, an increase in soil moisture produced very little effect upon the number of days from planting to heading. When a fertilizer high in nitrogen was added, the increased amount of moisture produced a decided increase in the number of days from planting to heading. A high nitrogen fertilizer added at the first stage decreased the length of this period fifteen days in the low moisture series and only three days in the high moisture series under that of no treatment.

In general, the length of the period from planting to heading was shortest where the fertilizers were added at the first stage as compared with where the same fertilizers were added at later stages. See Fig. 27.

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* The date of heading refers to the time when six plants per pot were in head.

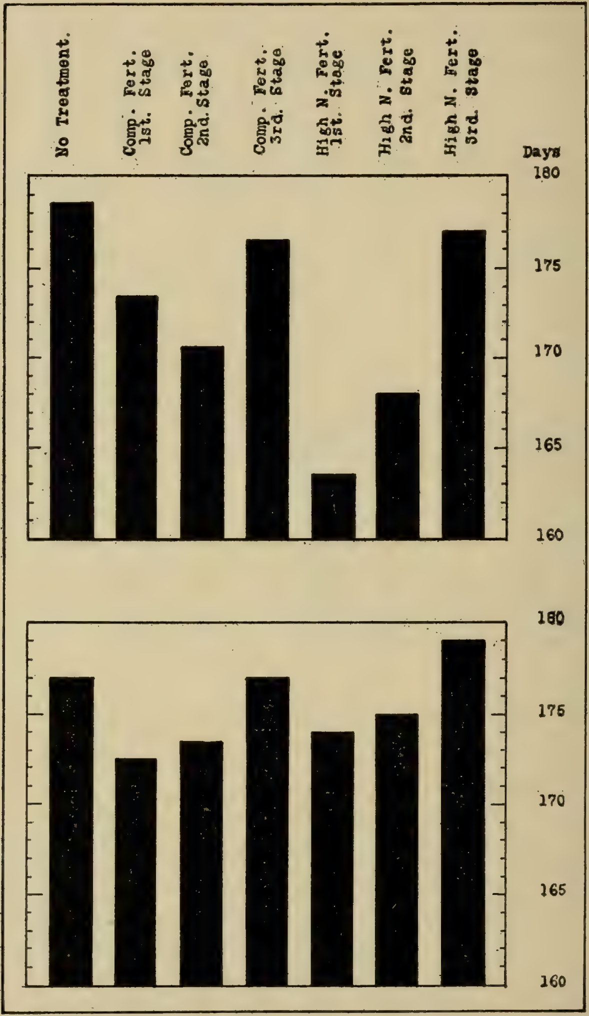

FIG. 27.—Number of days from planting to heading (wheat) under different conditions of soil moisture and fertilization.

When the plants were mature, measurements were taken to determine the influence of the various treatments upon the average length of culms from surface of soil to the base of the spikes and also upon the average length of spikes.

Table XXIX gives the data as regards the length of culms. See Fig. 28.

Increasing the moisture content of the soil from 17.6 percent to 42.8 percent has increased the average length of culms from 26.8 inches to 37.7 inches.

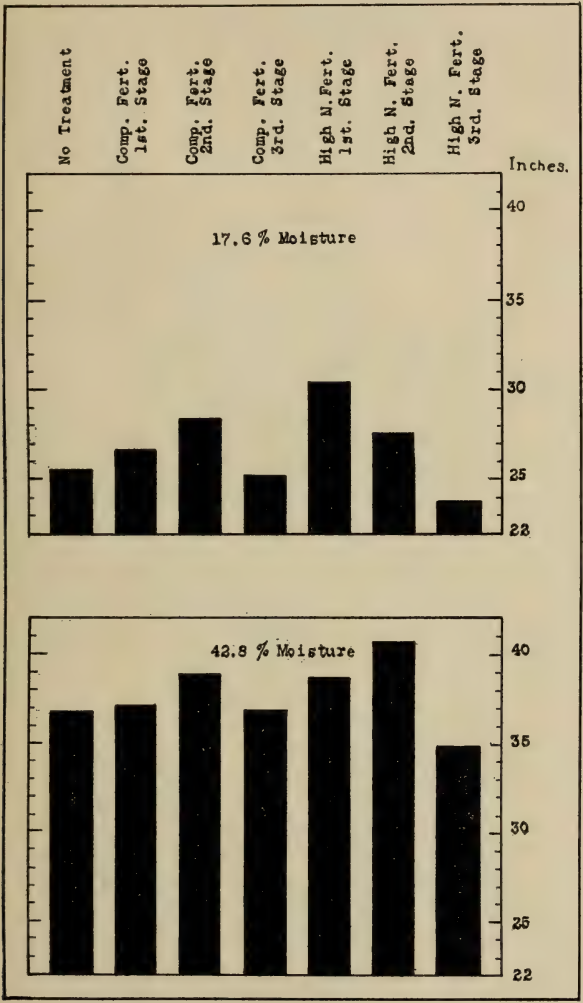

FIG. 28.—Average length of culms (wheat) under varying conditions of soil moisture and fertilizations.

The complete fertilizer has produced the maximum length of culms in both low and high soil moisture when added at the beginning of the second stage of growth. When added at the beginning of the third stage, the length of culms in both low and high soil moisture was slightly less than where the fertilizer was added at planting and also less than where no fertilizer was applied.

TABLE XXIX.—*Showing the Influence of Soil Moisture and the Different Fertilizer Treatments upon the Average Length of Wheat Culms (Inches).*

| Treatment | Length of Culms. | | |
|---|---|---|---|
| | 17.6 Percent W. | 42.8 Percent W. | Average. |
| Comp. fert. 1st stage | 26.7 | 37.1 | 31.9 |
| Comp. fert. 2d stage | 28.4 | 38.9 | 33.6 |
| Comp. fert. 3d stage | 25.1 | 36.9 | 31.0 |
| No fertilizer | 25.5 | 36.8 | 31.1 |
| High N fert. 1st stage | 30.4 | 38.7 | 34.5 |
| High N fert. 2d stage | 27.5 | 40.7 | 34.1 |
| High N fert. 3d stage | 23.9 | 34.9 | 29.4 |
| Average | 26.8 | 37.7 | |

Where the high nitrogen fertilizer was applied to the low moisture soil the maximum length of culms was produced in the pots to which the application was made at the time of planting. When the application was made at the beginning of the second stage of growth, the length of culms was less than fertilizer at first stage but greater than fertilizer at third stage and where no treatment was given. The high nitrogen in the high moisture series produced the greatest length of culms when applied at the beginning of the second stage; the second greatest length where the application was made at time of planting; the third greatest where no treatment was given and the minimum length where the fertilizer was added at beginning of third stage.

Table XXX shows the influence of the various treatments upon the length of spikes.

TABLE XXX.—*Showing the Influence of Soil Moisture and the Various Fertilizer Treatments Upon the Average Length of Wheat Spikes (Inches).*

| Treatment. | Length of Spikes. | | |
|---|---|---|---|
| | 17.6 Percent W. | 42.8 Percent W. | Average. |
| Comp. fert. 1st stage | 3.20 | 3.29 | 3.24 |
| Comp. fert. 2d stage | 3.43 | 3.61 | 3.52 |
| Comp. fert. 3d stage | 3.21 | 3.74 | 3.47 |
| No fertilizer | 2.68 | 3.33 | 3.00 |
| High N fert. 1st stage | 3.44 | 3.38 | 3.41 |
| High N fert. 2d stage | 3.17 | 3.83 | 3.50 |
| High N fert. 3d stage | 3.23 | 3.69 | 3.46 |
| Average | 3.19 | 3.55 | |

The complete fertilizer in low moisture soil has produced the maximum length of spikes when applied at the beginning of the second stage. Where it was applied at planting, the spikes were slightly shorter than where the application was made at the beginning of the third stage, but much larger than where no fertilizer was applied. The results from the addition of a complete fertilizer to the high moisture soil is even more strikingly in favor of the later applications, the maximum length of spikes being produced where

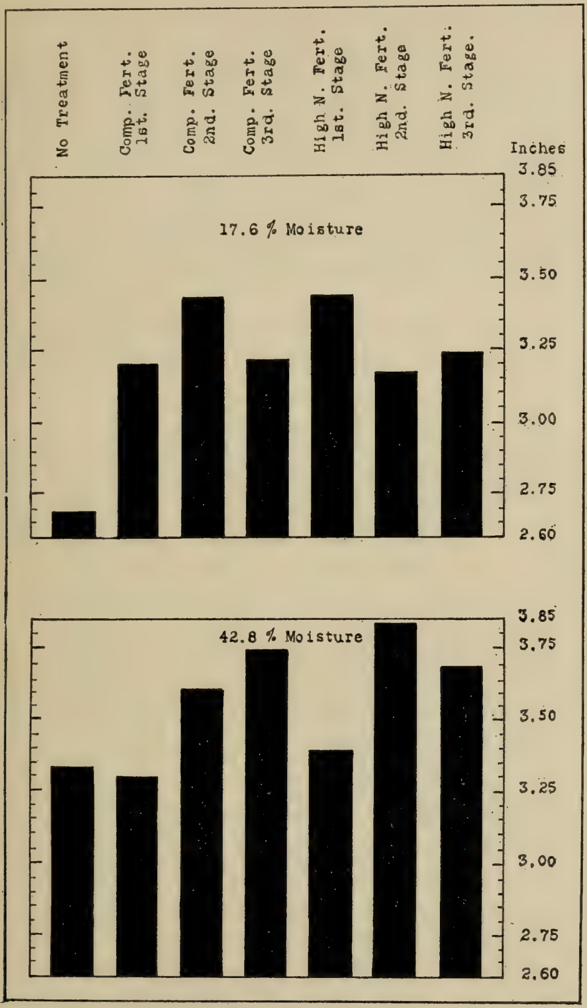

FIG. 29.—Average length of spikes (wheat) produced under different conditions of soil moisture and fertilization.

the fertilizer was added at the beginning of the third stage. A complete fertilizer at the second stage produced larger spikes than one applied at planting. The peculiar thing is that where no fertilization was given the average length of spikes was greater than where a complete fertilizer was added when the grain was planted. (See Fig. 29.)

The later applications of a high nitrogen fertilizer to the low moisture soil have not proven beneficial as compared with this form of nitrogen applied at time of planting, the length of spikes being reduced. However, when this same fertilization was given to the high moisture soil, the later applications have been more effective than that given at time of planting, the maximum length being produced as a result of adding the high nitrogen fertilizer at the beginning of the second stage.

The plants were harvested when mature and the grain separated from the straw. Table XXXI gives the yields of both grain and straw.

TABLE XXXI.—*Showing the Influence of Soil Moisture and the Various Fertilizer Treatments Upon the Yield of Straw and Grain (Grams).*

| Treatment. | 17.6 Percent W. | | 42.8 Percent W. | |
|---|---|---|---|---|
| | Grain. | Straw. | Grain. | Straw. |
| Comp. fert. 1st stage....... | 12.79 | 46.90 | 26.49 | 99.12 |
| Comp. fert. 2d stage....... | 15.63 | 52.79 | 28.58 | 99.13 |
| Comp. fert. 3d stage....... | 14.65 | 42.81 | 29.03 | 91.37 |
| No fertilizer............... | 9.93 | 33.12 | 23.74 | 82.71 |
| High N fert. 1st stage...... | 16.84 | 63.50 | 30.18 | 116.28 |
| High N fert. 2d stage...... | 15.40 | 54.80 | 31.66 | 126.47 |
| High N fert. 3d stage...... | 13.46 | 42.22 | 33.68 | 111.35 |

The increase in soil moisture from 17.6 percent to 42.8 percent has greatly increased the production of both grain and straw.

It is quite interesting to notice the very favorable effects which the later applications of fertilizers have produced, especially as regards grain, as compared with fertilizing at the time of planting. In both low and high moisture soils the complete fertilizer produced a heavier yield of grain when applied at the second and third stages than when applied at the time of planting. The results are somewhat different with the straw, the yield on the high moisture soil decreasing as the period of growth at which the fertilizer treatments were given advances. However, there was a higher yield of straw on the low moisture soil from the pots fertilized at the second stage than from those fertilized at planting. Where fertilization was given to the low moisture soil at the third stage, the yield of straw dropped below the other fertilized pots but was higher than the untreated pots.

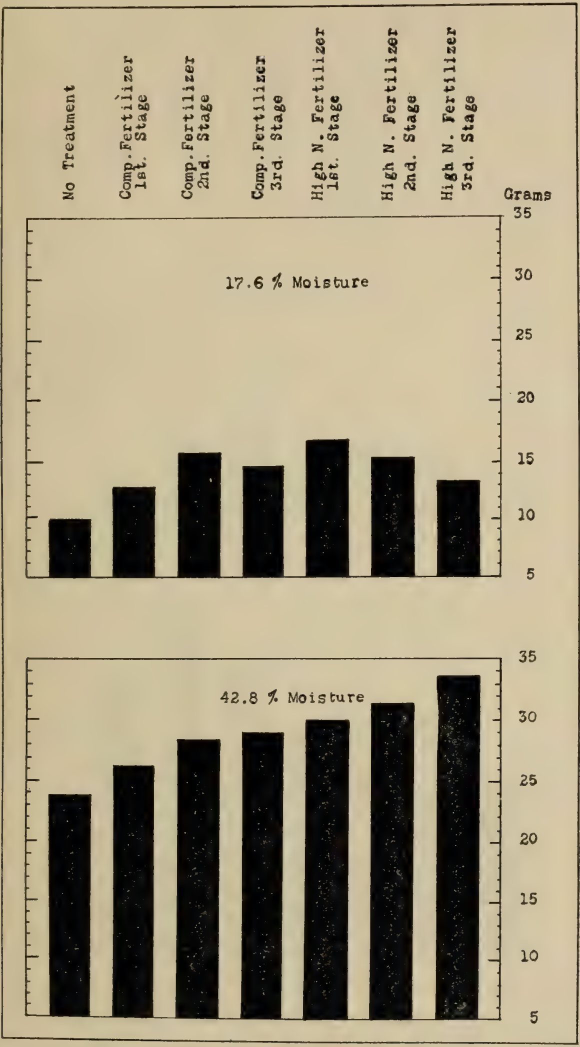

FIG. 30.—Yield, in grams, of grain (wheat) under varying conditions of soil moisture and fertilization.

The high nitrogen fertilizer, when applied to the low moisture soil at the second stage of growth, has not produced as high a yield of either grain or straw as when applied at planting. However, when this same fertilizer was applied to the high moisture soil at the second stage, the yield of grain and straw was higher than when applied at planting. (See Figs. 30 and 31.)

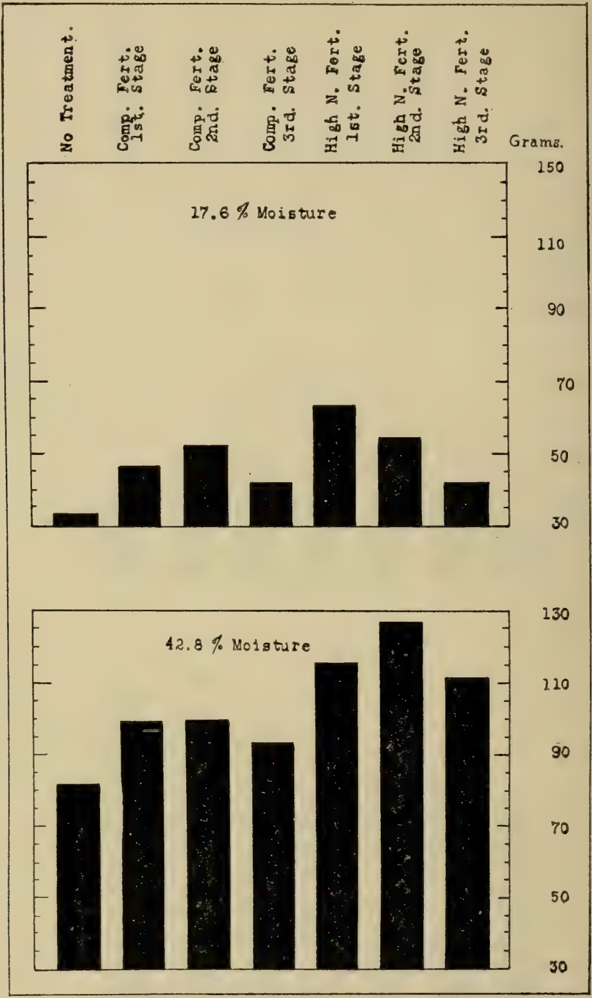

FIG. 31.—Yield, in grams, of straw (wheat) produced under different conditions of soil moisture and fertilization.

The crop growing in the soil with a low moisture content showed a slightly higher percentage of nitrogen in the grain where the complete fertilizer was added at the time of planting than when added at a later date. Where the high nitrogen fertilizer was added to the low moisture soil there seemed to be a tendency for the percent nitrogen in grain to increase with the later applications. The lowest percentage of nitrogen in grain was found where no fertilizer was added.

TABLE XXXII.—*Showing the Influence of Soil Moisture and the Various Fertilizer Treatments Upon the Percent Nitrogen in Grain and Straw.*

| Treatment. | Percent Nitrogen. | | | |
|---|---|---|---|---|
| | 17.6 Percent W. | | 42.8 Percent W. | |
| | Grain. | Straw. | Grain. | Straw. |
| Comp. fert. 1st stage....... | 2.86 | 0.465 | 2.10 | 0.735 |
| Comp. fert. 2d stage....... | 2.80 | 0.515 | 2.04 | 0.285 |
| Comp. fert. 3d stage....... | 2.80 | 0.475 | 2.13 | 0.285 |
| No fertilizer............... | 2.74 | 0.590 | 2.36 | 0.315 |
| High N fert. 1st stage...... | 2.84 | 0.530 | 2.50 | 0.315 |
| High N fert. 2d stage...... | 2.86 | 0.595 | 2.30 | 0.315 |
| High N fert. 3d stage...... | 2.87 | 0.615 | 2.16 | 0.310 |
| Average.................. | 2.82 | 0.541 | 2.23 | 0.366 |

The straw shows results somewhat more variable than were found with the grain, but here also we notice the tendency for the later applications of a high nitrogen fertilizer to the low moisture soil to increase the percent nitrogen in plant over that found in plants to which the fertilizers had been applied at the first stage.

In the high moisture soil the results are somewhat different. With the later applications of a high nitrogen fertilizer, the percent nitrogen in crop decreases. This is more marked in the grain than straw. Where the complete fertilizer was added at the first stage the straw contained 0.735 percent nitrogen as compared with 0.366 percent as an average for the entire high moisture series which is strange.

In low soil moisture the grain showed an average of 2.82 percent nitrogen, while the high moisture series averaged only 2.23 percent. The same differences are noticeable in the straw. The results of analyses made of crops harvested at the different stages of growth have not yet been obtained. (See Figs. 32 and 33.)

TABLE XXXIII.—*Showing Effect of Fertilizer Treatment and Soil Moisture Upon Root Development.*

| Treatment. | Weight in Grams, of Air Dry Roots. | |
|---|---|---|
| | 17.6 Percent W. | 42.8 Percent W. |
| Comp. fert. 1st stage.................... | 22.5 | 13.4 |
| Comp. fert. 2d stage.................... | 20.5 | 11.4 |
| Comp. fert. 3d stage.................... | 21.4 | 16.4 |
| No fertilizer........................... | 22.3 | 14.5 |
| High N fert. 1st stage.................. | 27.3 | 14.9 |
| High N fert. 2d stage.................. | 26.7 | 19.3 |
| High N fert. 3d stage.................. | 25.2 | 30.2 |
| Average............................. | 23.7 | 17.1 |

When the plants were harvested the soil in each pot was placed upon a sieve of rather fine mesh and carefully washed from around the roots by means of a gentle stream of water. This was done so that none of the roots was lost. The roots were then thoroughly air dried and weighed.

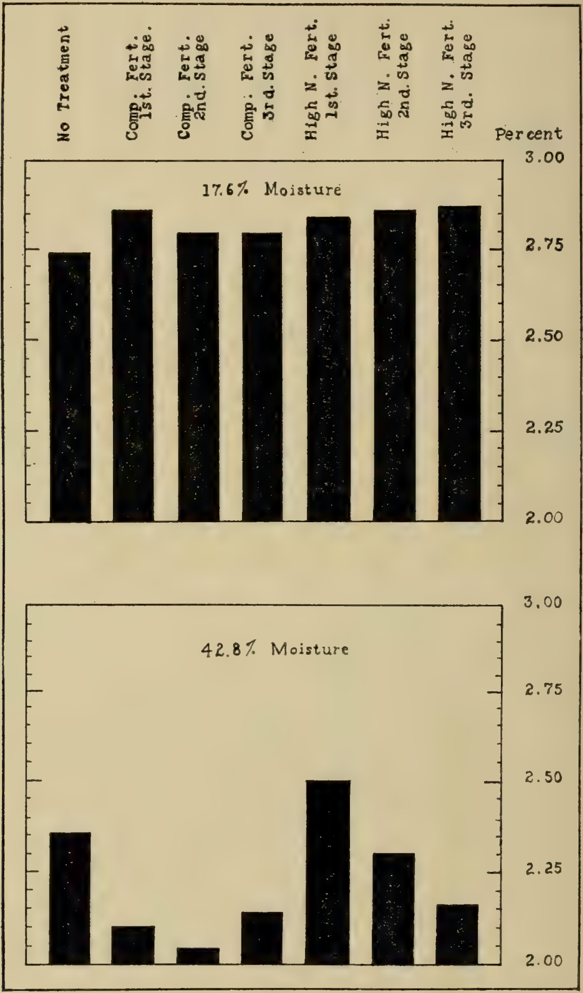

FIG. 32.—Percent nitrogen in grain (wheat) when grown under varying conditions of soil moisture and fertilization.

Table XXXIII shows that the moisture content of the soil influenced the root development more than did the fertilizers or the time of their applications. However, the high nitrogen fertilizer when applied to the plants growing in the high moisture at the later stages of growth, has produced a considerably greater root development than when applied at planting time. This same fertilizer when applied to the low moisture soil has given opposite results. The complete fertilizer has produced results which are not very consistent and no definite conclusions can be drawn. There is a much greater root development in the low than in the high moisture soil, which of course would have been expected. (See Fig. 34.)

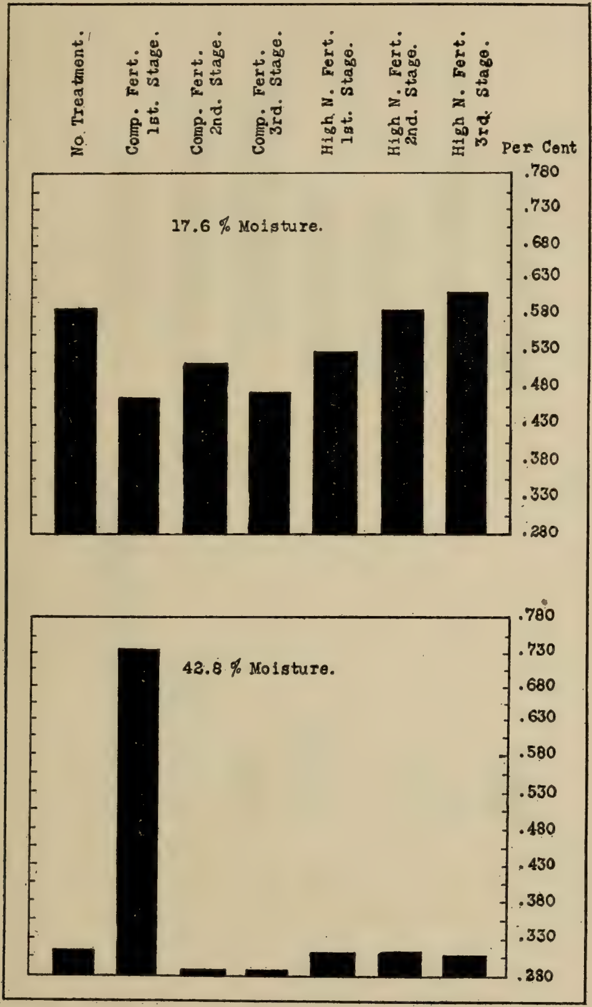

FIG. 33.—Percent. of nitrogen in straw (wheat) when grown under varying conditions of soil moisture and fertilization.

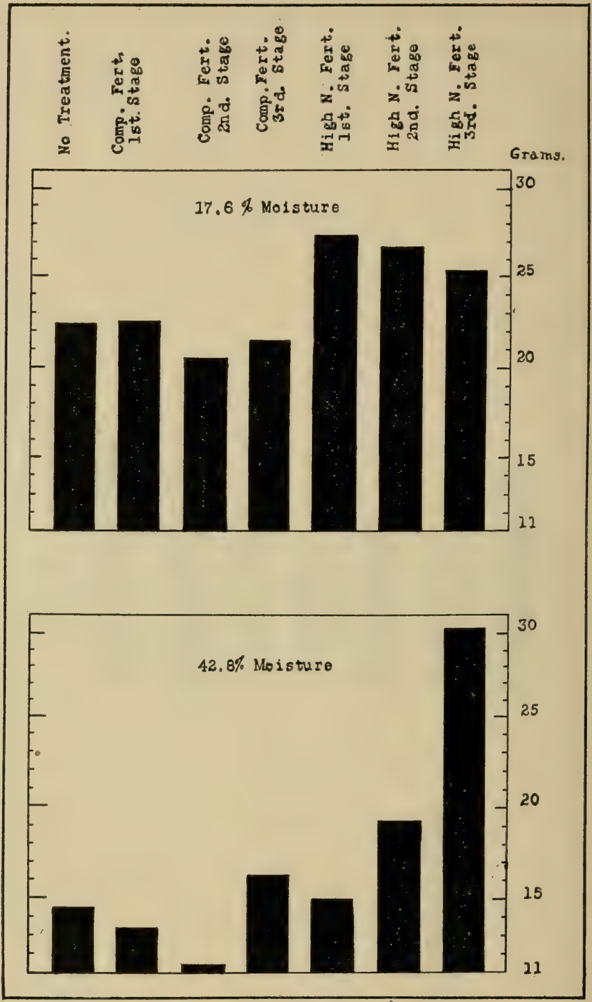

FIG. 34.—Production, in grams, of air-dry roots from plants (wheat) grown under different conditions of soil moisture and fertilization.

## SUMMARY.

1. Increasing the soil moisture increased the length of time from planting to heading two days in case of oats and three days in case of wheat.

2. Increasing the soil moisture has decreased the stooling of the oats and increased the stooling of wheat.

3. Increasing the soil moisture has greatly increased the production of dry matter.

4. Increasing the soil moisture has greatly reduced the percentage increase in yield due to fertilizers.

5. The percentage increase in yield due to potassic and phosphatic fertilizers has decreased more rapidly following an increase in soil moisture than has that due to nitrogenous fertilizers.

6. An increase in soil moisture has greatly decreased the percentage of dry matter in plants.

7. The amount of dry matter produced per gram of transpiration is greater in a medium than in a low or high moisture soil.

8. Increasing the soil moisture decreased root growth.

9. The high moisture soil, being more compact, was a better conductor of heat than the low moisture soil.

10. The heat traverses the soil largely by means of conductivity.

11. An increase in soil moisture decreased the percentage of nitrogen in plants following the application of a nitrogenous fertilizer and increased it following the application of a mineral fertilizer.

12. A high nitrogen fertilizer applied to a relatively dry soil increased very markedly the percentage of nitrogen in crop grown. This is not so marked on a high moisture soil.

13. The percentage of nitrogen in crop decreases as the yield of crop increases and vice versa, *unless* the increased yield is the result of abundant nitrogen in a low moisture soil.

14. Increasing the soil moisture increased the grams total nitrogen produced in crop.

15. The albuminoid nitrogen in crop behaved very much as the total nitrogen.

16. A complete fertilizer added to soils of both low and high moisture content has been most effective when applied either at the time the plants possessed five well-developed leaves or later when they showed evidence of heading.

17. In a soil of low moisture content a high nitrogen fertilizer produced its best results when applied at time of planting crop, but produced a greater yield of straw in the high moisture soil when applied when the plants possessed five well-developed leaves, while the highest yield of grain was produced where the fertilizer was applied just before heading.

# APPLICATION OF WILTING COEFFICIENT DETERMINATIONS IN AGRONOMIC INVESTIGATONS.

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In all agronomic investigations in which the water supply may become a limiting factor in the development of a crop, it is desirable to determine from time to time the amount of water in the soil that is available for plant growth. It is well known that the available moisture cannot be found simply by making determinations of the total soil moisture content. The soil still retains a part of its initial moisture supply even when the plant cover has been reduced to a wilting condition. Furthermore, the amount of moisture which remains in the soil at this time depends upon the soil type. The variation of moisture retentivity with soil type is so great that it is unsafe to make a direct comparison of moisture determinations without first having established by physical examination that the soils in question have the same moisture retentivity. The moisture equivalents[1] of extreme types, as measured recently by the writers,[2] ranged from 1.5 percent for coarse sand to 57 percent for the heaviest types of clay, which illustrates the great range in moisture retentiveness that may be encountered in field work.

If we assume that growth practically ceases when the plant has been reduced to a permanently wilted condition, then the moisture content of the soil at the time of the permanent wilting of the plant cover becomes the datum from which the moisture available for growth in that soil is calculated. The moisture content of the soil at the time when the permanent wilting of the plant first occurs has been termed by the writers the wilting coefficient of that soil for the particular plant used as an indicator.[3] We have found that the wilting coefficient, like the moisture equivalent, varies widely with the soil type. Our recent determinations give a range of from less than one percent in sand to thirty percent or more in heavy types of clay. In fact the wilting coefficient may be considered as a measurement of the moisture retentiveness of the soil, using a physiological method instead of the physical methods generally employed.

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[1] Briggs, Lyman J. and J. W. McLane. Moisture equivalent determinations and their application. Proc. Am. Soc. Agron. 2: 138 (1910), 1911.

[2] Briggs, Lyman J. and H. L. Shantz. The wilting coefficient for different plants and its indirect determination, U. S. Dept. Agr., Bur. Plant Indus., Bul. 230, 1912.

[3] For a fuller discussion of these determinations and the precautions to be observed, see the paper cited in footnote 2.

With the soil-moisture content ranging at the time of the wilting of the plant cover from less than one percent to more than thirty percent according to the type of soil, it is very evident that soil moisture determinations made for the purpose of establishing the available moisture in the soil, mean absolutely nothing unless the wilting coefficient is also known. Unfortunately this fact has not been appreciated in much of the soil-moisture work that has heretofore been conducted and, as a result, the determinations are, as a rule, incapable of interpretation. Loughridge[4] and Alway[5] have appreciated the necessity of applying to soil-moisture determinations a correction for the amount that is not available to the growing plant, and in the absence of more definite information, have assumed the hygroscopic coefficient of the soil as the lower limit of available moisture. This constituted a decided step in advance but, as we shall show later, the hygroscopic coefficient is less than the moisture content of the soil at the time the plant wilts and the approximation may result in a considerable error in determining the water supply available for growth.

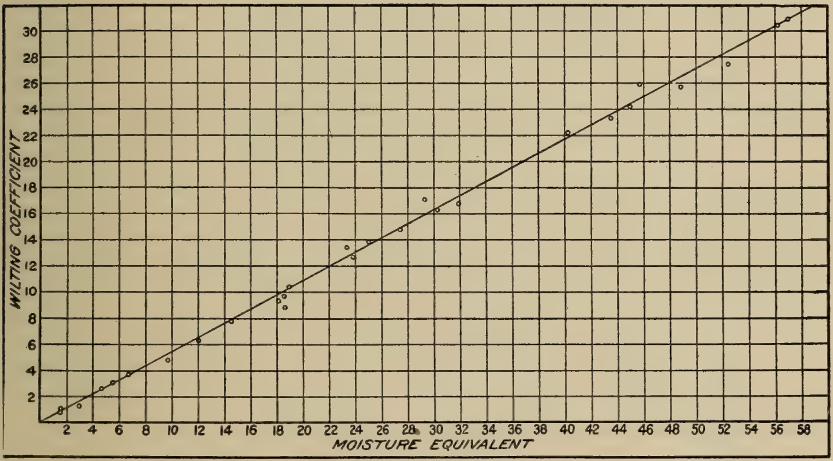

FIG. 35.—Linear relationship between the wilting coefficient and the moisture equivalent. (From U. S. Dept. Agric. Bur. Plant Indus. Bul. 230.)

Reference has already been made to the fact that the wilting coefficient can be looked upon as a physiological measure of the moisture retentivity of the soil. This is supported by the writers' determinations of the wilting coefficient and of the moisture equivalent for a series of soil types of widely varying texture. These determinations are given in Tables I and II and are also shown graphically in Fig. 35, in which the wilting coefficient and the moisture equivalent are used as coördinate axes. The resulting graph is a straight line through the origin, showing that the wilting coefficient increases in direct proportion to the moisture equivalent. The tangent of the angle of the graph with the horizontal axis is the reciprocal of 1.84. This relationship can then be expressed by the equation

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[4] Loughridge, R. H. Moisture in California soils during the dry season of 1898. California Sta. Rept. for 1897–8, page 66, 1900.

[5] Alway, F. J. Studies of soil moisture in the "Great Plains" region. Jour. Agr. Sci. 2: 334, 1908.

$$\text{wilting coefficient} = \frac{\text{moisture equivalent}}{1.84(1 \pm 0.007)}.$$

The second term of the quantity within the parentheses indicates the probable error of the ratio.

Table I.—*The Relation of the Wilting Coefficient to the Moisture Equivalent in Soils Ranging from Sand to Clay-loam.*

| No. | Soil Type. | Moisture Equivalent. | Wilting Coefficient. | | Ratio of Moisture Equivalent to Wilting Coefficient. |
|---|---|---|---|---|---|
| | | | No. of Observations. | Mean. | |
| 1 | Coarse sand | 1.6 | 11 | 0.9 | 1.78 |
| 2 | Fine sand | 4.7 | 16 | 2.6 | 1.81 |
| 3 | Fine sand | 5.5 | 3 | 3.3 | 1.67 |
| 4 | Fine sand | 6.7 | 2 | 3.6 | 1.86 |
| 5 | Sandy loam | 9.7 | 9 | 4.8 | 2.02 |
| 6 | Sandy loam | 11.9 | 3 | 6.3 | 1.89 |
| 7 | Fine sandy loam | 18.1 | 13 | 9.7 | 1.87 |
| 8 | Loam | 18.9 | 3 | 10.3 | 1.83 |
| 9 | Sandy loam | 19.6 | 1 | 9.9 | 1.98 |
| 10 | Fine sandy loam | 19.9 | 1 | 10.8 | 1.84 |
| 11 | Fine sandy loam | 22.1 | 1 | 11.6 | 1.90 |
| 12 | Loam | 25.0 | 12 | 13.9 | 1.80 |
| 13 | Loam | 27.0 | 1 | 15.2 | 1.78 |
| 14 | Clay loam | 27.4 | 2 | 14.6 | 1.88 |
| 15 | Clay loam | 29.3 | 4 | 16.2 | 1.81 |
| 16 | Clay loam | 30.0 | 1 | 16.5 | 1.82 |
| 17 | Clay loam | 30.2 | 16 | 16.3 | 1.85 |

Mean.................................1.84
Probable error of mean...............±0.013

The direct determination of the wilting coefficient requires experiments extending over several weeks, and certain precautions must be observed to insure satisfactory results.[6] The plants should be grown in impervious pots with the soil surface sealed with wax to prevent direct loss of moisture, and the pots should be kept in a stirred bath of water to avoid differences in temperature between the soil mass and the walls of the pot. Accurate determinations of the wilting coefficient under field conditions appear to be impossible, since there is no certainty as to what part of the soil the plant is relying upon for its moisture supply at the time of wilting. The indirect determination of the wilting coefficient by means of the moisture equivalent is, therefore, much more convenient than the direct determination and leads to results that are sufficiently accurate for field use in calculating the available moisture supply. The moisture equivalent determinations are quickly and easily made, so that the uniformity of the soil as regards moisture retentiveness can be checked as often as desirable. This is a point much in favor of the indirect method, since, in the most uniform soils with which the writers have worked, it is exceptional not to encounter differences in the moisture retentivity in different samples even if taken from the same part of the plat. This is also the case in deep sampling, the different 1-foot sections often showing progressive changes in the moisture retentiveness.

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[6] Briggs, L. J. and H. L. Shantz. A wax seal method for determining the lower limit of available soil moisture. Bot. Gaz. 51: 210–219, 1911. Also paper cited in footnote 2.

TABLE II.—*Relation of the Wilting Coefficient to the Moisture Equivalent of Heavy Clay Soils from Bellefourche, South Dakota.*

| Sample No. | Moisture Equivalent. | Wilting Coefficient. | | Ratio of Moisture Equivalent to Wilting Coefficient. |
|---|---|---|---|---|
| | | No. of Observations. | Mean. | |
| *P* | 31.9 | 3 | 16.8 | 1.89 |
| *Q* | 40.2 | 2 | 22.2 | 1.82 |
| *R* | 43.5 | 3 | 23.3 | 1.86 |
| *S* | 44.9 | 2 | 24.2 | 1.85 |
| *T* | 45.7 | 3 | 25.9 | 1.78 |
| *U* | 48.8 | 3 | 25.7 | 1.90 |
| *V* | 52.4 | 3 | 27.4 | 1.91 |
| *W* | 56.2 | 3 | 30.4 | 1.84 |
| *X* | 57.0 | 3 | 30.9 | 1.84 |

Mean.............................1.85
Probable error of mean............±0.02

Linear relationships, similar to that found between the wilting coefficient and the moisture equivalent, have also been established for the hygroscopic coefficient, the moisture-holding capacity, and the moisture retentivity of the soil as expressed in terms of the mechanical composition, as follows:[7]

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[7] The data upon which these relationships are based will be found in Bulletin 230, cited above in footnote 2.

$$\text{Wilting coefficient} = \frac{\text{hygroscopic coefficient}}{0.68(1 \pm 0.018)}$$
$$= \frac{\text{moisture holding capacity} - 21}{2.90(1 \pm 0.021)}$$
$$= \frac{0.01\ \text{sand} + 0.12\ \text{silt} + 0.57\ \text{clay}}{(1 \pm 0.025)}.$$

The hygroscopic coefficient as used above, is taken to represent the water content of the soil (initially dry) after having been brought into equilibrium with a saturated atmosphere at a constant temperature (approximately 20° C.).

The moisture-holding capacity is defined, following Hilgard,[8] as the maximum percent of water which a column of soil 1 cm. in height is able to retain at a temperature of 20° C. in opposition to the force of gravity. This determination is considerably influenced by the manner of packing.

In the indirect method for determining the wilting coefficient from the mechanical composition, the terms sand, silt and clay refer to the percentage of these several groups as shown by the mechanical analysis. The "sand" includes particles 2–0.05 mm. in diameter; the "silt" particles 0.05–0.005 mm.; and the clay all particles less than 0.005 mm. diameter.

In each equation the second number of the quantity within the parentheses denotes the probable error of the ratio. It will be seen that none of the relationships is as accurate as that between the wilting coefficient and the moisture equivalent.

## FIELD APPLICATION OF WILTING COEFFICIENT DETERMINATIONS.

The application of wilting coefficient determinations to the interpretation of soil moisture measurements[9] is illustrated in Fig. 36, which represents a series of daily moisture determinations made in 1-foot sections to a depth of six feet at Akron, Colorado, during the season of 1910. Kubanka wheat was growing upon the plat in which the soil moisture determinations were made. The heavy horizontal line in each chart shows the wilting coefficient of the soil for that particular section. This wilting coefficient was determined indirectly for each section from moisture equivalent determinations upon a composite of all the samples taken from that section. No rains of conse-

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[8] Hilgard, E. W. Soils, 1906, p. 209.

[9] See also Shantz, H. L. The natural vegetation as an indicator of the capabilities of land for crop production in the Great Plains area. U. S. Dept. Agr., Bur. Plant Indus., Bul. 201, 1911, pp. 30–33.

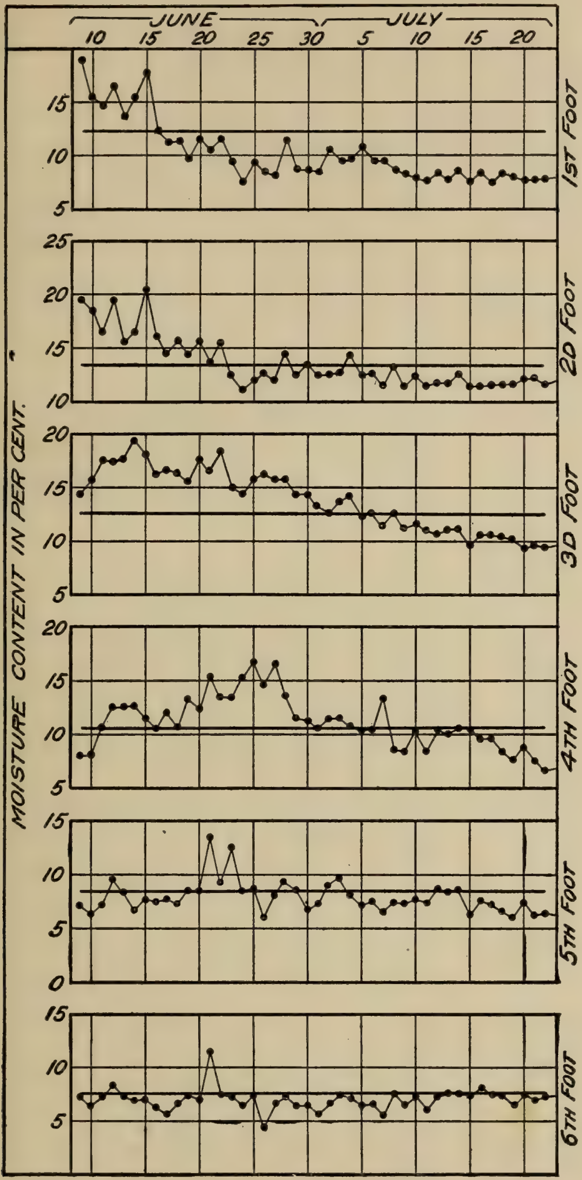

FIG. 36.—Daily moisture determinations in a Kubanka wheat plat to a depth of 6 feet, and the calculated wilting coefficient (heavy horizontal line) for each foot. The wheat wilted July 1. (From U. S. Dept. Agric. Bur. Plant Indus. Bul. 230.)

quence occurred during the time covered by the chart. The chart shows that the upper foot of soil was first reduced to its wilting coefficient, followed in order by the second, third and fourth feet. There is also an indication that a small amount of water was removed from the fifth foot during the last part of the experimental period. On July first the crop was beginning to wilt. The horizontal lines representing the wilting coefficient are, on this date, practically coincident with the soil moisture curves, with the exception of the first foot, which had dried out below the wilting coefficient. In other words, the wilting coefficient determined by an indirect method after the close of the season's work, is in agreement with the observed soil moisture content at the time of wilting.

From these results and from the independent determinations of the ratio of the moisture equivalent to the wilting coefficient, given in Table I, it appears justifiable to use this indirect method of establishing the datum from which to compute the available moisture of the soil.

Attention is called to the variation in the wilting coefficient of the different 1-foot soil sections shown in the chart. The first and third feet are the same, but a successive reduction occurs in the lower sections. A little reflection will show the futility of attempting to base conclusions upon soil moisture determinations without the aid of the wilting coefficient of each section as the datum from which to compute the available moisture supply.

Owing to the variation of the moisture retentivity of the soil at any given depth, the wilting coefficient is not a constant as assumed in the above discussion, but varies from point to point in the soil. In moisture determinations, therefore, the moisture equivalent should be determined frequently, particularly if there is any evidence of a progressive change in texture in the section in which the successive samples are being taken for moisture determinations. In our later work we have made moisture equivalent determinations on each sample taken in the soil moisture work.

Reference to the chart shows that, with a continuance of the drought, the moisture curves passed below the wilting coefficient. In the case of the first foot, this is probably largely due to evaporation from the surface of the soil. The corresponding loss in the case of the second, third and fourth feet, we attribute to the loss taking place through the plant tissues, the wheat not being harvested until July 22. Laboratory determinations which we have made show that there is a steady loss of water going on through the plant from the soil to the air long after wilting takes place, and even after the upper portions of the plant are apparently air-dry. It is for this reason that we have preferred to use the term wilting coefficient as referring to the moisture content at the wilting point, rather than the old term "non-available moisture," since moisture which the plant is constantly removing from the soil can hardly be considered non-available.

The results of some of the soil moisture determinations made in the Great Plains during the summer of 1911, which was extremely dry, indicate that a crop is capable, under certain conditions, of reducing the moisture content of a part of the soil below the wilting coefficient, before the crop actually wilts. The condition appears to develop after the crop has reduced the water content of the second and third feet to the wilting coefficient, but still has water available at lower depths. This may be explained from a consideration of the conditions which produce wilting. A plant wilts when its transpiration exceeds its absorption, although the soil is still supplying moisture, and continues to do so for some time, but not fast enough to maintain the turgor of the plant. However, if the plant is constantly extending its root system into moist soil, it will continue to remove water from the drier zone without wilting. In this way the drier zone may be reduced considerably below the wilting coefficient. It follows that the amount of moisture available for growth may be somewhat greater than that calculated by the use of the wilting coefficient as a datum.

It often happens under field conditions and also when plants are grown in large pots that at the approach of a drought the lower leaves die very gradually. This self pruning continues in extreme cases until the entire leaf area is dead. Often the general wilting of the plant can not be observed during this whole process. Under these conditions the wilting point is at best indefinite, and the soil moisture content is usually reduced far below the wilting coefficient before the death of the plant. The water which is removed from the soil after the moisture content has been reduced to the wilting coefficient may result in some growth but this is so small in proportion to the water consumption that it is of little practical value from the stand-point of crop production.

### *Variation in the Wilting Coefficients of Soils of Adjacent Plats.*

The differences which may be encountered in the moisture retentiveness of the soils of adjacent plats are well illustrated in the data in Table III.

Table III.—*Wilting Coefficients of Soils at Dickinson Experiment Substation, North Dakota, Showing the Differences in the Moisture Retentiveness of the Subsoil of Adjacent Plats.*

| Plat. | Wheat. | | | | Oats. | | | |
|---|---|---|---|---|---|---|---|---|
| | *A* | *B* | *C* | *D* | *A* | *B* | *C* | *D* |
| 1st foot | 11.6 | 11.4 | 12.2 | 11.8 | 10.7 | 10.8 | 10.5 | 10.7 |
| 2d foot | 11.7 | 11.7 | 11.8 | 12.2 | 9.8 | 10.1 | 10.2 | 11.0 |
| 3d foot | 11.8 | 12.2 | 11.8 | 11.2 | 8.4 | 7.9 | 10.5 | 11.1 |
| 4th foot | 11.4 | 13.0 | 12.7 | 12.5 | 7.5 | 9.0 | 9.5 | 11.7 |
| 5th foot | 10.6 | 12.4 | 13.9 | 13.5 | 7.7 | 8.4 | 7.4 | 9.0 |
| 6th foot | 9.4 | 11.1 | 12.6 | 12.9 | 9.3 | 8.1 | 6.5 | 7.9 |

The plats referred to form a part of the cooperative cultivation experiments being conducted by the Office of Dry Land Agriculture at Dickinson, North Dakota, and under virgin cinditions appeared to be very uniform. Each plat is two rods wide and eight rods long. The four wheat plats are arranged side by side and end to end with the corresponding oat plats. The figures in the table represent the wilting coefficient of the soil of each plat in one-foot sections to a depth of six feet, calculated from moisture equivalent determinations made upon composite samples from each depth. It will be seen that the wilting coefficients of the soils of the oat plats in the first foot are about one percent less than the soils of the wheat plats, and that the differences become greater and greater for lower depths. Thus two of the oat plats in the third foot show a wilting coefficient three percent lower than the wheat plats, and two percent lower than the remaining two oat plats. The wilting coefficient of oat plat *C* in the fifth and sixth feet is six percent lower than the corresponding wheat plat at the same depths.

### *Differences in the Wilting Coefficients of Soils and Subsoils.*

Great differences sometimes occur in the wilting coefficients of the soil and subsoil of the same plat. An extreme case of this kind is found on the experiment farm at Bellefourche, South Dakota, as shown by the determinations given in Table IV.

The wilting coefficients were calculated from the moisture equivalents by means of the relationship established in Table II. It will be noted that the fourth, fifth and sixth feet (Table IV) have much higher wilting coefficients than the upper three feet. Before the wilting coefficient determinations on these soils were available, it had been assumed that the deeper layer of soil contained an abundance of available moisture, which the crop, for some unknown reason, was unable to remove. The fact that this heavy subsoil seems moist as it comes from the sampling tube, even when reduced to its wilting coefficient, appeared to support this assumption. Actual determinations, however, showed that the moisture content of the subsoil did not exceed the wilting coefficient, which accounted fully for the failure of the crop to effect any further removal of water from this layer. In other words, it is possible for this heavy soil to hold thirty percent of moisture so tenaciously that none of it is available for the growth of plants.

TABLE IV.—*Wilting Coefficients of Soils at Bellefourche Experiment Farm, South Dakota, Showing the Great Increase in Moisture Retentiveness of the Subsoil at Depths Below 3 Feet.*

| Plat. | Wheat. | | | | Corn. | | | |
|---|---|---|---|---|---|---|---|---|
| | *A* | *B* | *C* | *D* | *A* | *B* | *C* | *D* |
| 1st foot | 17.4 | 17.1 | 17.3 | 17.0 | 15.4 | 16.0 | 16.4 | 16.4 |
| 2d foot | 17.8 | 16.4 | 16.8 | 17.1 | 15.5 | 16.8 | 17.3 | 16.2 |
| 3d foot | 14.9 | 13.9 | 15.6 | 17.0 | 15.9 | 15.3 | 17.4 | 16.2 |
| 4th foot | 20.9 | 22.0 | 19.9 | 21.9 | 22.3 | 23.1 | 23.6 | 21.2 |
| 5th foot | 24.4 | 29.7 | 30.2 | 25.5 | 22.9 | 27.8 | 25.6 | 24.2 |
| 6th foot | 31.4 | 26.5 | 30.5 | 33.1 | 28.5 | 28.1 | 32.2 | 31.0 |

It would consequently be impossible to draw reliable conclusions regarding the influence of moisture upon the development of crops on the field plats mentioned above without a knowledge of the wilting coefficients of these different soils. It is evident from an inspection of the table that very erroneous conclusions would be reached from an assumption that the soils and subsoils were uniform.

The issue may be raised that the wilting coefficient is not of general applicability, because it varies with the kind of plant used. This variation appears to be much less than has heretofore been supposed. The writers have recently[10] examined a large number of crop plants with a view to determining their variation in this respect, and find that taking 100 to represent the average wilting coefficient of all the great crop plants, the maximum is represented, by 107 for Esperanza corn, and the minimum by 92 for Japan rice. Most of the crops and varieties tested are in much closer agreement than this. For the purpose in hand, therefore, the wilting coefficient can be assumed, without serious error, to be practically the same for all crop plants. The plant used in establishing the ratios employed in the equations was Kubanka wheat (U. S. Grain Investigations No. 1440) which gives a value almost identical with that obtained for the mean of all the plants used.

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[10] See footnote 2.

## Use of Moisture Relationships in Class Instruction in Agronomy.

Although a digression from the subject of this paper we desire to add a word regarding the applicability of the relationships given above to class-room instruction in crops and soils. In experiments dealing with soil moisture there is, at the present time, a lack of correlation. The student makes determinations mainly by empirical methods, and leaves the subject without an appreciation of the interrelationships of the different properties of the soil. As we have already stated, all of the determinations which have been discussed in this paper may be looked upon as different ways of measuring the moisture retentiveness of a given soil, and by means of the relationships established it is possible for a student to intercompare his different determinations in the case of any particular soil. For example, the student may make a mechanical analysis of a soil, and from this mechanical analysis may calculate its wilting coefficient. He may also determine the wilting coefficient of the soil directly for comparison with his computed value. The moisture retentiveness of this soil may also be measured directly by the moisture equivalent method, using the centrifugal machine, and this value, in turn, may be used as a basis for an indirect determination of the wilting coefficient. Similar indirect determinations may be made following the measurement of the hygroscopic coefficient and the moisture-holding capacity of the soil in question, and finally, the different determinations may be directly compared by means of subsidiary formulæ, which are given elsewhere.[11]

The writers believe that such determinations when applied to soils of widely varying texture, may serve to develop in the student a keener interest and appreciation of the moisture relationships of soils and the bearing of such relationships upon crop production.

Discussion by R. O. E. Davis:

The point should be emphasized that the wilting of a plant, which is made the basis for the determination of the moisture content below which the plant does not maintain healthy growth, is dependent on many factors. The wilting is due to excess of transpiration over absorption of water. The rate of transpiration depends on temperature, humidity, and wind velocity, size of leaves, number of stomata, and the concentration of the cell solution. The rate of absorption is affected by the character of the soil, the concentration of soil solution and of cell solution, the temperature, and the character of the plant roots.

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[11] Briggs, Lyman J. and H. L. Shantz. The wilting coefficient and its indirect determination. Bot. Gaz. 53: 20–37. Jan., 1911. Also footnote 2.

# METHODS OF DETERMINING THE WATER REQUIREMENTS OF CROPS.

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Perhaps the earliest conception regarding the source from which crops draw their nutrition was that it came from the soil. Of course the necessity of water in crop production was recognized from the first, but in what way it was utilized by the crop was more or less of a mystery. Van Helmont, about the year 1600, demonstrated, however, to his satisfaction that plants did not live on soil but live on water. He did this by planting a willow tree in a tub, watering it as need be, and at the end of five years he again weighed the willow tree and the soil in his tub. He found that the willow had gained 168 pounds while his soil has lost only a few ounces, and, as water had been the only constituent added to the soil, he therefore concluded that plants must live on water and not from the soil. From his time to the present, considerable interest has been shown in this subject among those interested in plants and crop growing. In 1847 the Rothamsted Experiment Station[1] conducted a series of experiments to determine the amount of water required by plants for a given increase in dry weight. From that time up to the present, a great many experiments have been made, the work being carried on in particular between the years 1860 and 1880, when a number of eminent experimenters were working along this line in Germany, prominent among these investigators being Hellriegel, Wollny and Haberlandt. At the same time, numerous experiments have been made by plant physiologists and various forms of apparatus devised to be used in laboratories or greenhouses. The following illustrations and data are not intended as a complete or a technical discussion of the subject, but merely as a brief account of the various methods which have been used; the apparatus employed; and some of the factors that have modified results. Finally, a method is suggested for carrying on such work in the field.

It is a well-known fact that each stoma of a leaf is connected with an intercellular air-space so that there is a free movement of the atmospheric air in and out of the leaf. This is a continuous process in the living plant and removes the surplus moisture exuded into the air passages.

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[1] Rothamsted Memoirs, Field Experiments, Vol. 1, 1847–1863.

### *Demonstrating Water Loss from Cut Leaves.*

Fig 37 illustrates two methods used in demonstrating the loss of water from leaves. *a* is a simple apparatus, made by clamping the leaf between two pieces of glass with a small piece of cobalt paper. After the paper has been clamped on the leaf a few minutes, the glass plates are removed, and the fact that water has come through the leaf is demonstrated by the paper changing color. By this means it can be determined that water loss may take place from one or both sides of the leaf. *b* illustrates a method of determining the exact amount of water exuded from two sides of a leaf. Two inverted bell jars are affixed to the leaf, with vaseline around the edges. In the two watch glasses a water absorbent is placed, as calcium chloride. After the leaf has been allowed to transpire a given length of time, the amount of water loss is determined by reweighing the watch glass. Table I gives some data secured by this last apparatus. It is shown in this that the number of stomata is not always an indicator of the relative amount of water loss for a comparison of the loss from a leaf of *Tilia europæa* and from one of *Hedera helix* shows, in the former case, considerable loss from the upper surface, even though there are no stomata present, and a fairly large loss from the lower surface.

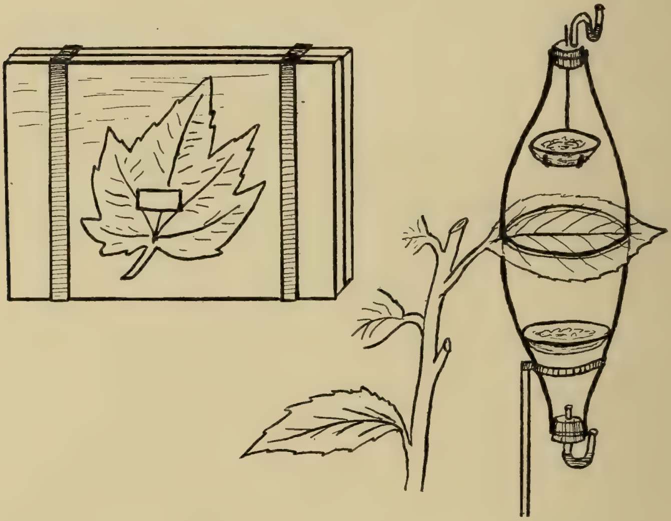

FIG. 37.—Illustration of methods used in proving water loss from leaves.

TABLE I.—*Number of Stomata and Relative Amount of Water Lost From the Leaves of Plants.*

| Plant. | Area of Transpiring Leaf-surface in Sq. Cm. | Relative No. of Stomata Present. | Grams of Water Transpired in 24 Hrs. |
|---|---|---|---|
| *Atropa belladonna* | 40 | Upper 10 | 0.48 |
| | | Under 55 | 0.60 |
| *Syringa vulgaris* | 20 | Upper 100 | 0.30 |
| | | Under 150 | 0.60 |
| *Tilia europæa* | 20 | Upper 0 | 0.20 |
| | | Under 60 | 0.49 |
| *Hedera helix* | 20 | Upper 0 | 0.00 |
| | | Under 90 | 0.04 |

In the latter case, however, there is no water loss from the upper surface and a very small loss from the lower surface, even though it is well supplied with stomata. The number and size of the stomata is not an indicator of the probable loss of water from a given leaf area when different species or varieties are compared. It is not very common that water is lost through an epidermis when no stomata are present, but this is true in a few cases.

### *Determining Water Loss from Cuttings.*

Fig. 38 illustrates also the methods of determining water loss from cuttings. *a* is merely a U-tube with a tight rubber cork in each leg.

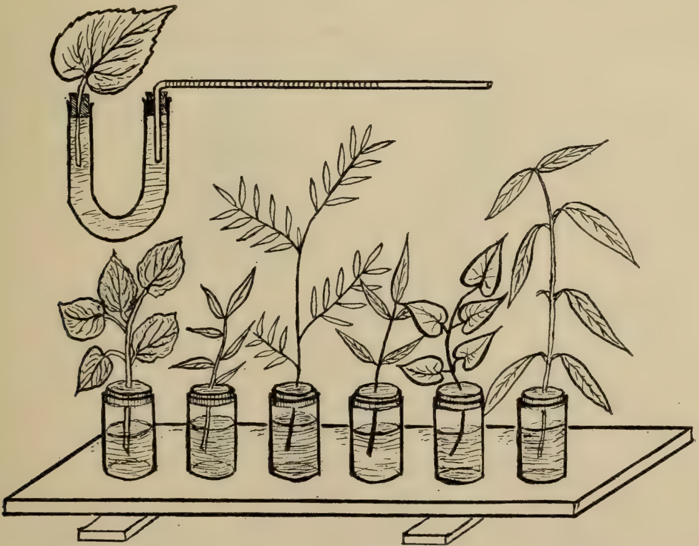

FIG. 38.—Illustration of methods of determining water loss from cuttings.

It is necessary that the branch or leaf to be tested be so inserted that it is airtight. The small tube is scaled so that the amount of water required by the leaf or branch can be determined from time to time. *b* figures a very simple apparatus for determining water loss. Wide-mouthed bottles with ordinary corks can be utilized. A battery of this kind of evaporimeter can be quickly set up, and is convenient for comparing the relative loss between different varieties of plants under varying conditions, such as shade and sunshine. Of course the records can only be taken for one or two days before the cutting wilts, but the method is often very useful.

### *Methods of Determining Water Loss Where Growing Plants are Used.*

Fig. 39 illustrates three methods which have been utilized for this purpose. *a* is a small flowerpot with a growing plant. After the plant has been well watered, the top of the pot is covered with a rubber cloth to prevent evaporation. Hourly or daily water loss can be determined by weighing, until the plant has used all the available water in the pot. The experiment may be continued by renewing the water supply. *b* shows the wire basket method of growing seedlings, the wire basket and surface being covered with paraffin to prevent

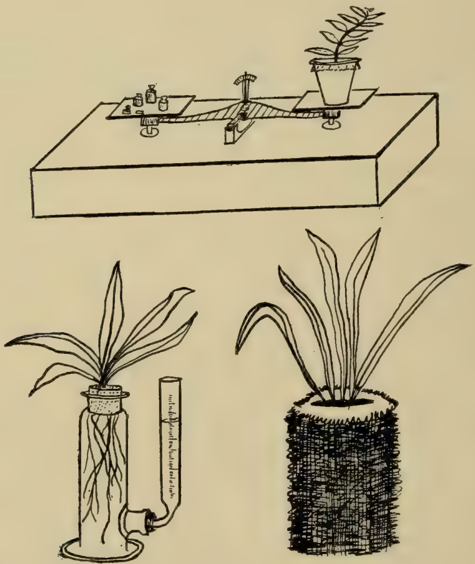

Fig. 39.—Illustration of methods of determining water loss from growing plants.

evaporation from the soil, and water is added as needed, through the opening where the plants are growing. *c* illustrates a method of growing the plant in a culture solution and determining the water loss by measuring the change in level on the graduated siphon. By renewing the culture solution from time to time, a very normal plant can be grown in this way for several days or even weeks.

### *Automatic Methods of Securing a Record of the Water Loss.*

No less than eight automatic methods for determining water loss have been devised, some of which are quite elaborate and two of which are here illustrated. In *a,* Fig. 40, the plant is balanced by a counterpoise hanging in a jar of water. The counterpoise is of exactly one square centimeter in cross area, so that the sinking of the counterpoise one centimeter into the water displaces exactly one cubic centimeter. The time at which this displacement takes place is recorded on a smoked drum operated by clock work. In *b* the water is drawn into the evaporimeter through a siphon, the amount lost between each reading being indicated on the graduated hygrometer.

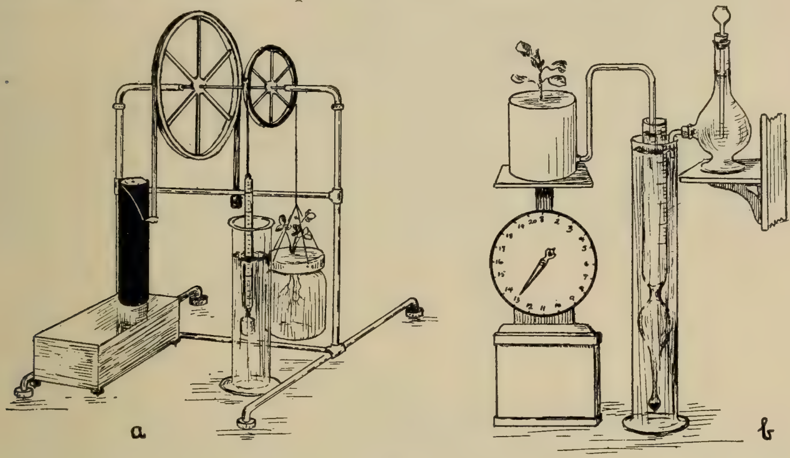

FIG. 40.—Automatic apparatus for determining loss of water from plants.

Fig 41 illustrates three types of large jars which have been used at the Nebraska Experiment Station. *a* is a 5-gallon water jar filled with soil. In the bottom an inverted flowerpot is placed, with two glass tubes, through one of which the water is poured. The surface of the soil around the plant is covered with several layers of paraffin paper, to prevent evaporation. One difficulty with growing plants to maturity in jars covered with paraffin is that no aeration is secured and the plant does not grow normally. The roots also tend to collect around the outside of the jar. By having the inverted flowerpot in the center, complete aeration is secured, with only a small loss by evaporation, and the roots are distributed normally. *b* illustrates a large can, 36 inches in depth, to be used in the field. Gravel is placed at the bottom and the water is supplied continuously from a 5-gallon jar placed beside it. After the plant is well started, gravel is placed on the surface to prevent the rise of water by capillarity, and the whole is covered with a metal lid. In the case of large plants like maize, the water is prevented from running down the stalk of the plant into the can by the use of sculptor's clay,[2] which is quite adhesive and is plastered around the base of the plant and over the lid, as illustrated in Fig. 47. Plate III, Fig. 1, shows one of the 5-gallon jar evaporimeters in section with the apparatus necessary for making water determinations. This apparatus has been used for growing corn plants almost to maturity, with very good success.

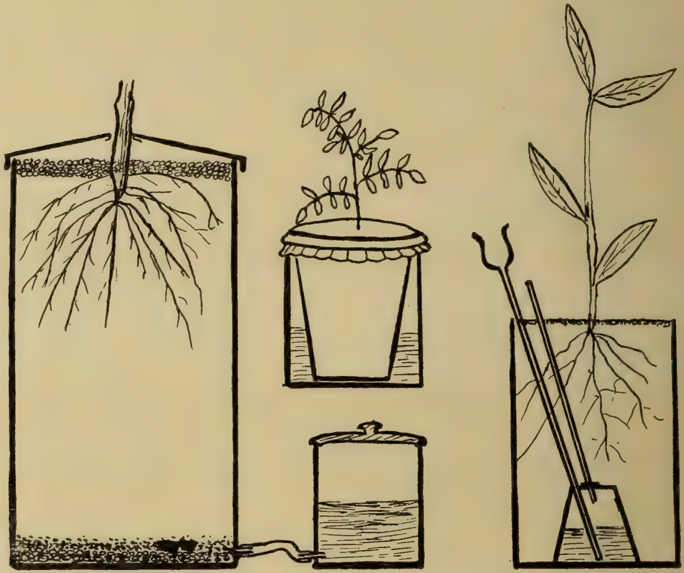

FIG. 41.—Three types of evaporimeters, for growing plants to maturity.

*Field Methods for Determining the Loss of Water from Field Crops.*

Fig. 42 illustrates the method used by King at the Wisconsin Station. At first, vinegar barrels were sunk into the midst of the fields

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[2] "Composite" molding clay. A. H. Abbott and Co., Chicago.

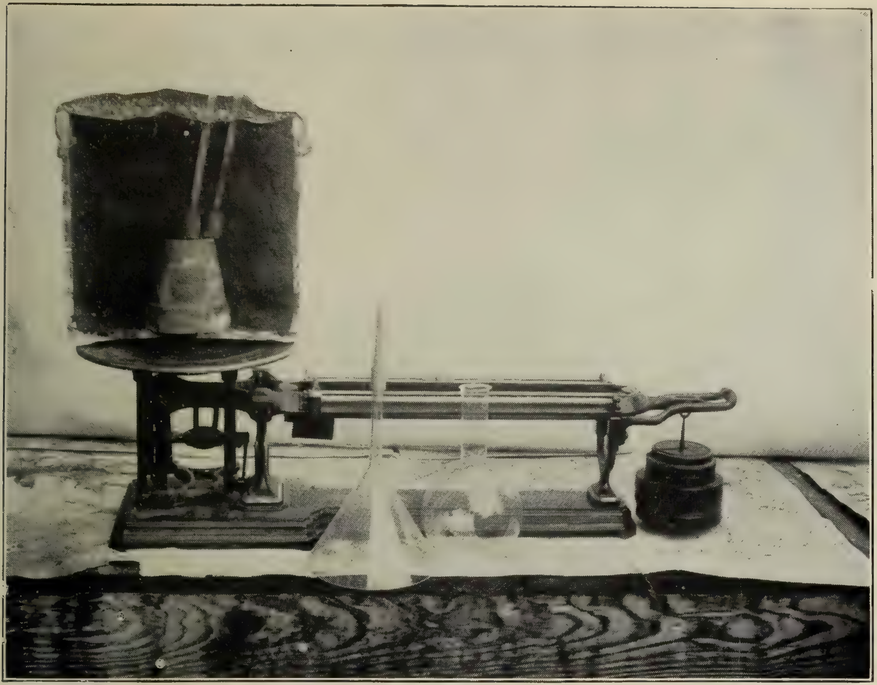

FIG. 1.—An evaporimeter made from a five-gallon jar (shown in section) with apparatus necessary for making determinations. (Courtesy Nebraska Exp. Sta.)

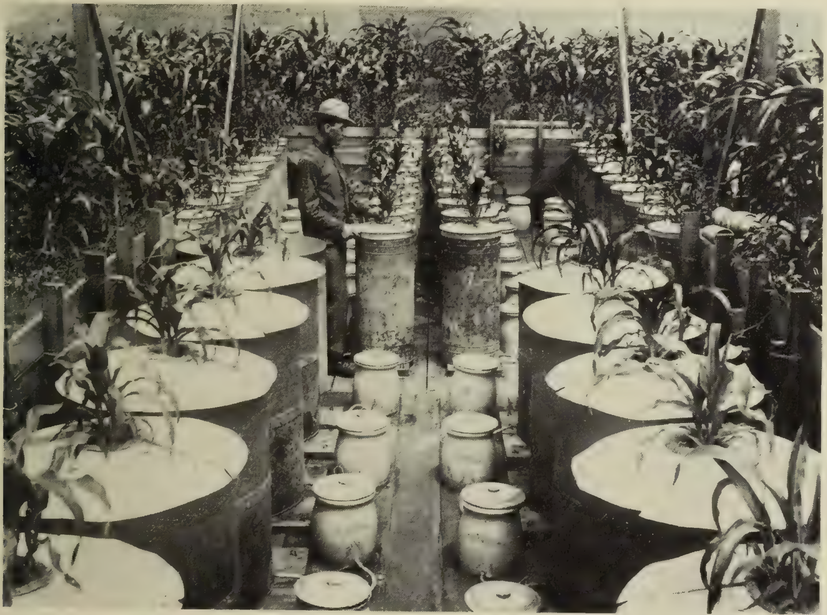

FIG. 2.—Series of cans used at the Nebraska Experiment Station in determining water requirements of maize plants.

and a derrick fixed for weighing occasionally. Water was added as needed. In his later experiments he made cans 42 inches deep, out of galvanized iron, and had a 4-inch tile placed inside of each and extending to the bottom, through which the water was added as needed. He adopted the plan of watering the plants from the bottom by the use of a tile, because he found in adding water from the surface a very large percent was lost by evaporation. Plate III, Fig. 2, illustrates a series of large cans at the Nebraska Experiment Station. The largest ones are 36 inches deep and 30 inches in diameter, holding 1,000 pounds of dry soil, or about 1,400 when saturated to the optimum water content.

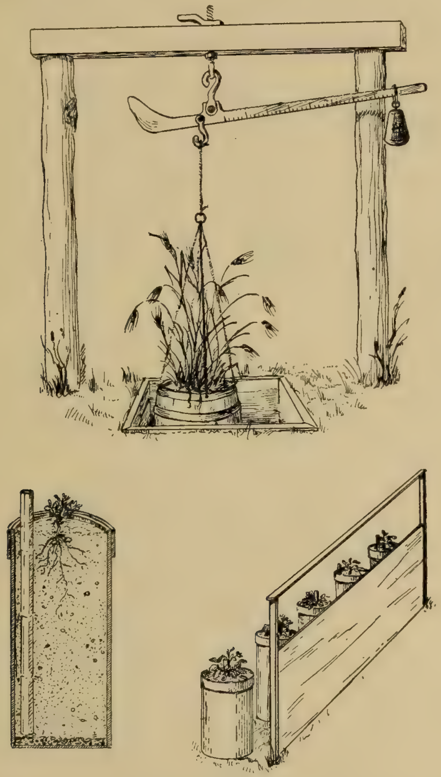

Fig. 42.—Apparatus used by King in Wisconsin in making water determinations.

Fig. 43 illustrates a method used first at the Utah Experiment Station and later at the Montana Experiment Station. The cans were 36 inches deep and set in the ground so that the top of the can was level with the surface. However, a tub was first placed in the bottom of each hole and partly filled with water, with the idea that by surrounding the soil can by water it would be kept near the normal temperature of the surrounding soil. A heavy cable was stretched over the line of cans, and weighing was done by attaching to a weigh-

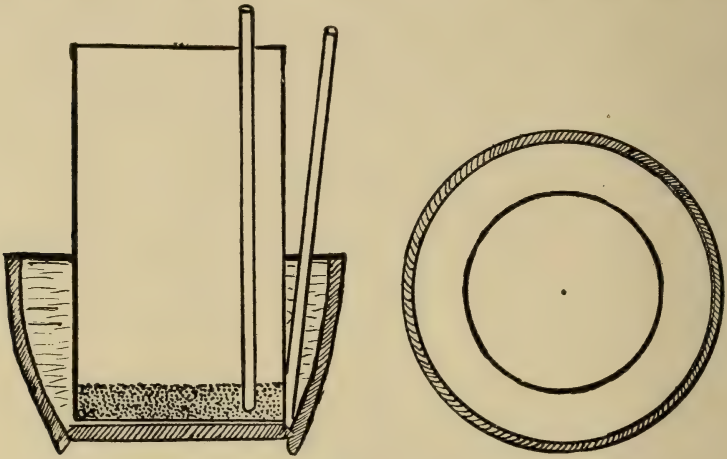

FIG. 43.—Method of arranging cans at the Montana Station.

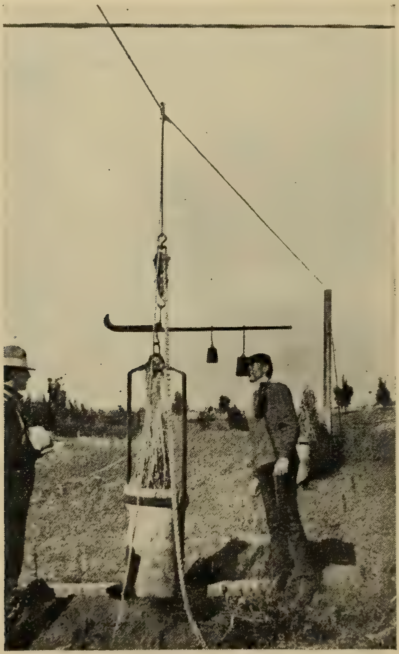

FIG. 44.—Weighing cans at Montana Experiment Station.

master's beam and raising by block and tackle. Fig. 44 shows one of these cans being weighed. A great many tub experiments and can experiments have been made, both in Europe and in America, using apparatus similar to that just described. In most of these experiments no attempt was made to prevent evaporation from the surface of the soil, and in some cases this was very large, amounting to perhaps twice as much as the water used by the plant. Table II shows some data from Bulletin 38 of the Montana Experiment Station indicating the amount of water lost by evaporation and the amount utilized by the crop. Only 12 to 31 percent of the water added was utilized by the crop, the rest being lost presumably by evaporation from the surface.

TABLE II.—*Proportion of Water Used By the Crop in Open Cans. Results by Fortier. (Montana Experiment Station, Bul. No. 38.)*

| Number of Tank. | Water Loss in Feet. | Difference in Feet. | Percent Water Used by the Crop. |
|---|---|---|---|
| 4. Wheat<br>10. Check can | 1.596<br>1.098 | .498 | 31 |
| 5. Wheat<br>11. Check can | 1.860<br>1.635 | .225 | 12 |
| 6. Wheat<br>12. Check can | 2.064<br>1.717 | .347 | 17 |

## *Error Due to Rainfall.*

Investigators soon found that, when their plants were grown in tubs in the open, natural rainfall, which was often heavy during the growing season, might cause a great amount of error as it was not possible to estimate accurately the amount of water received by each can from rainfall. To guard against this, plant houses of various types have been developed. Fig. 45 shows the plant house at Bernburg, Germany, and used by Hellriegel.[3]

The cans were mounted on heavy cars and pushed in and out of the plant house on a track. A somewhat similar plant house was used by Widtsoe at the Utah Experiment Station.[4] In these cases, however, evaporation from the surface of the soil was not prevented, and it is also known that water loss from the plant would be greatly reduced by putting the plants in a house as compared with leaving them in the open, under field conditions. With these sources of error recognized, there has been need for an apparatus which could be left in the open under field conditions which would exclude rainfall on the one hand and evaporation on the other, and at the same time permit a plant to mature normally. Fig. 46 illustrates a can devised at the Nebraska Experiment Station for this purpose. The can is 36 inches deep but could be made larger. A ⅜ inch copper coil, perforated every 8 inches, is placed in the can. Over each perforation a small piece of sponge is tied. Water is added by pouring the desired amount into a can attached to the upper end of the spiral. This method of distributing the water has several advantages. In the first place, it is uniformly distributed throughout the mass of soil. This is very important, especially where it is desired to keep the water content rather low. Experiment showed that when water was added it would distribute itself in a fairly uniform manner throughout the soil mass in about two hours. If the watering was done in the evening, plants requiring very little water during the night, the soil would be very uniformly moistened by morning. The coil also serves to aerate the soil. It has generally been found difficult to grow a plant to maturity in a normal way where cans were sealed up practically airtight in order to prevent evaporation, as the soil usually requires aeration for normal growth. Over the soil on the surface, about two or three inches of fine gravel are placed after the plants have been well started. All is then covered with a gal-

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[3] Exp. Sta. Rec., Vol. V, No. 8.

[4] Utah Exp. Sta. Bul. 105.

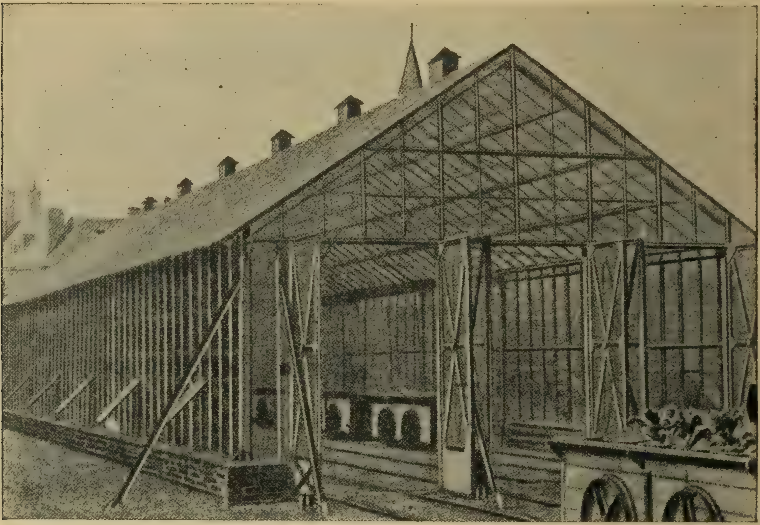

FIG. 45.—Plant house and trucks used in moving cans at Bernburg (Germany) Experiment Station. (Exp. Sta. Rec., Vol. V., No. 8.)

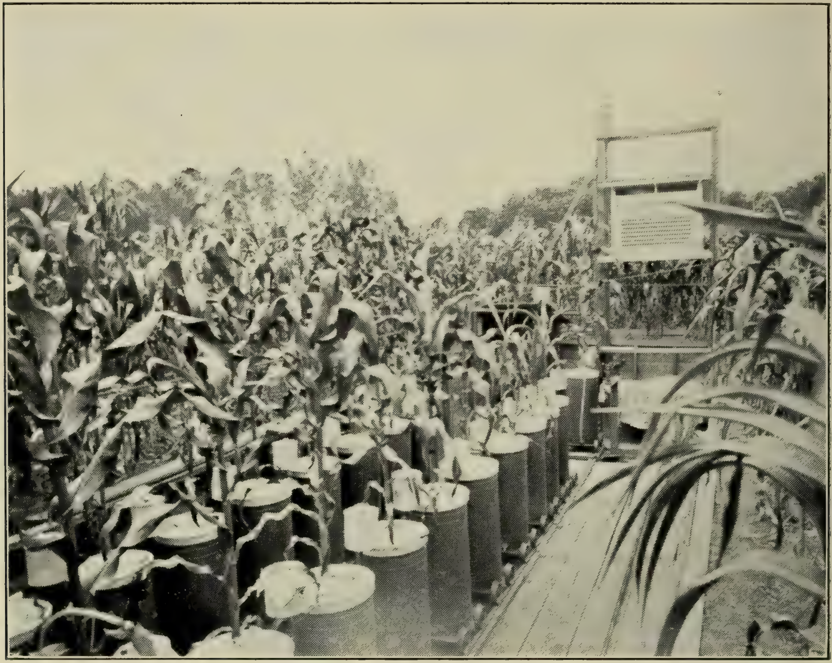

FIG. 1.—Battery of 24 cans used at the Nebraska Experiment Station (1910) in determining water requirements of crops in relation to weather factors. (Courtesy Nebraska Exp. Sta.)

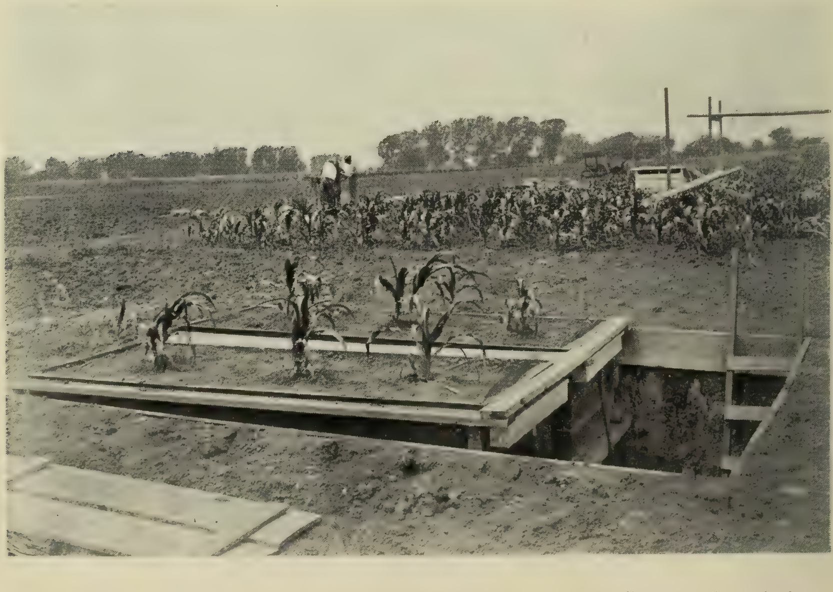

FIG. 2.—Large field cans used at Nebraska Experiment Station (1910) in determining rainfall, seepage, evaporation and transpiration.

vanized iron lid. These cans were used to grow corn plants, and rain was kept out by placing a mass of sculptor's clay around the plant. This is adhesive and at the same time pliable enough so that it does not interfere with the normal growth of the plant. Usually a collar of oilcloth was used to hold the clay in place. Fig. 47 shows the method of placing the sculptor's clay around the base of the plant. These cans have been used in the open, growing the plants for an entire summer without protection, and weighings before and after heavy rains have shown that no water enters the can. Also check cans have shown that practically no loss by evaporation from the surface takes place during the summer. Plate IV, Fig. 1, shows a battery of 24 of these cans mounted on trucks so that they can be weighed every day. Automatic instruments for recording weather and climatic conditions—hygrometers, thermometers, windgauges and raingauges—are kept in the instrument house. Plate IV, Fig. 2, shows two large cans, each 10 feet long, 3 feet wide and 6½ feet

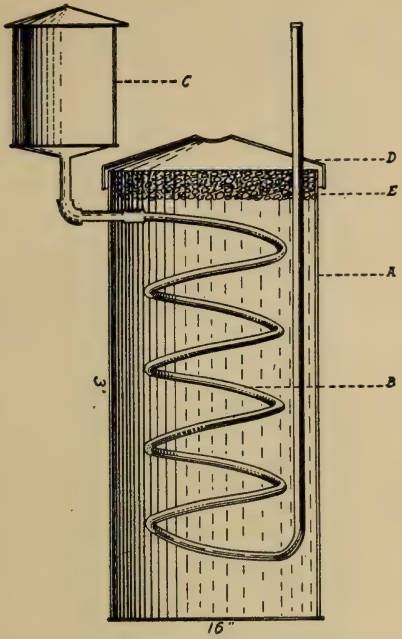

FIG. 46.—Diagrammatic vertical section of potometer. *a.* Galvanized iron soil can, 3 feet by 16 inches. *b.* Perforated spiral coil for distributing water in soil. *c.* Six-quart can through which all water is added. *d.* Lid with opening for plant. *e.* Three-inch gravel mulch for preventing water evaporation from soil surface. (From Nebr. Exp. Sta.)

deep, and holding about 8 tons of soil apiece. These cans are used to determine runoff and seepage as well as evaporation and transpiration. The ratio of transpiration to dry weight, is calculated from plants in adjacent cans. The exact ratio between dry weight and transpiration is determined each season, and in this way the amount of water lost by means of the plants can be calculated. Knowing the loss by seepage, runoff, and through the plant the rest of the water can be charged to evaporation from the soil.

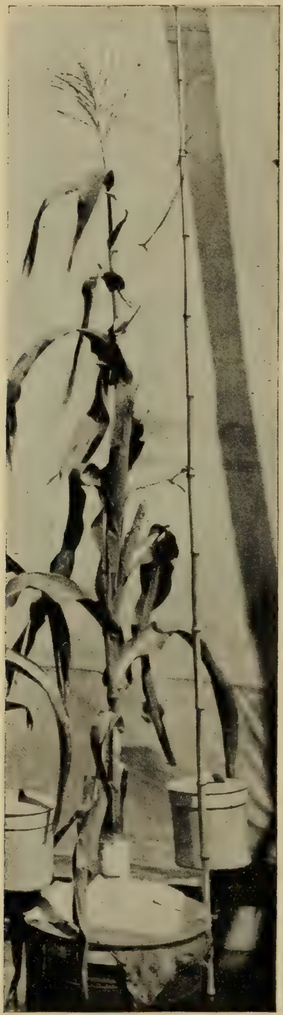

FIG. 47.—Maize plant in can showing method of placing sculptors' clay about the base of the plant.

A number of experimenters have attempted to determine the water requirements of crops by sampling the soil to a depth supposed to be below the root depth of the growing crop. King, of Wisconsin, laid off his field as shown in Fig. 48, and sampled to a depth of 6 feet, taking samples in foot sections. The soil was carefully sampled before the crop was planted, a record was made of the amount of water received by rainfall, and after the crop had been harvested the total amount of water in the soil was again determined by sampling. Of course this method is open to a great deal of error in cases where there is much runoff or seepage, but approximate results could be secured under conditions where the runoff or seepage during the growing season of the crop was small enough to be negligible or could be determined. Leather,[5] at Pusa, India, has used a similar method, sampling to the depth of 9 feet. In his case, very little rainfall comes during the growing season and he is able to get quite reliable results by this method. Here, however, the great difficulty has been to separate the water lost by evaporation from the soil surface and that lost through evaporation from the plants. Leather used a system of fallow plats alternating with his crop plats to determine the loss by evaporation from the surface.

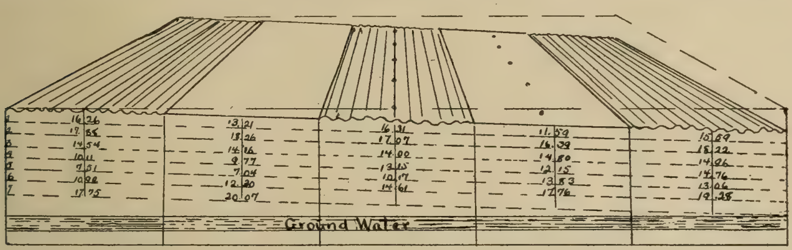

FIG. 48.—Method of laying out plats and method of sampling used by King at the Wisconsin Experiment Station. (Wis. Sta. Rpt. 1901, p. 92.)

## *Results Secured in Determining the Water Requirements of Crop.*

Results secured as to the amount or ratio of water required to produce a unit of dry weight have been quite variable. Most of this variation is probably due to the difference in amount of experimental error, as in almost every case evaporation lost from the surface of the soil has been added to that lost by the plant. Table III is a summary of some of the more important results secured, showing variation.

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[5] Leather, Walter J. Water Requirements of Crops, India 11. Agrl. Research Inst., Chemical Series, Vol. 1, No. 10, p. 230.

TABLE III.—*Amount of Water Required by Field Crops. A Summary of Results Obtained by Various Investigations.*

| | Results Obtained by Pot Culture. | | Results Obtained by Field Sampling. | |
|---|---|---|---|---|
| | Variation in Ratio of Water Required to Dry Wt. Produced as Reported by Lawes & Gilbert, Hellriegel, Wollny, King and Leather. | Result Obtained at Utah Experiment Station. Cans Used and Water Added. | Results by Ten Eyck—Kansas Experiment Station. 6 Foot Samples. | Results by Leather, Pusa, India. 9 Foot Samples. |
| Wheat ..... | 225–650 | 1,049 | 2,090 | 400–500 |
| Barley ..... | 262–774 | 1,208 | 2,152 | 340–440 |
| Oats ....... | 402–665 | | 1,295 | 230–330 |
| Corn ....... | 233–400 | 753 | 1,390 | |
| Red clover . . | 249–453 | | | |

In the first column it is noted that the highest factor in every case shows two or three times more water requirement than the lowest factor. A large part of this increase is probably due to the larger amount lost by evaporation from the soil rather than actual difference in loss from the plants. The second column shows results obtained at the Utah station. Here a very great water loss was obtained, but it is probable that it was due almost entirely to the great evaporation which must have taken place from the soil surface. The third column shows results secured by Ten Eyck with several crops grown under field conditions, in which he took 6-foot samples as heretofore described. In this case of course all sources of water loss were charged against the crop, as runoff, evaporation, seepage, as well as the water required by the plants themselves, and would necessarily equal the rainfall, plus the storage water used. The fourth column shows results secured with a similar method by Leather at Pusa, India, except that in his case very little rainfall came during the growing season, the crop living almost entirely on the stored water in the soil. Also his data represent water loss by the plants, as he has attempted to correct for water loss from the soil as heretofore described.

## *Some Factors Affecting Loss of Water from Plants.*

The time is at hand when more exact knowledge is required regarding the water requirements of crops under various climatic and soil conditions. There is sure to be a great deal of interest in this subject, due to the fact that a large proportion of the farming land west of the Missouri River that is now being settled is under conditions of deficient rainfall, where water is the most important single factor in crop production. It is estimated that 63 percent of the possible farming land of the United States is deficient in rainfall. Already a number of experiment stations are starting experiments to determine the water requirements of crops, and many more will be started, but unless some precaution is taken to do this work by a standard method it is likely that the results secured will be as variable and as difficult to draw definite conclusions from as those which have been secured in the past. It is my purpose to call attention to some of the conditions that modify results, and make suggestions From now on only cans should be used which prevent evaporation from the surface of the soil, so that the water lost by the plants can be exactly determined. Also, the cans should be placed under field conditions, not protected by buildings or trees. The height of the can above ground also will make a great deal of difference in results. Table IV shows the difference in water evaporation from a free water surface at several different heights from the ground. These data were secured in an ordinary cornfield, and cover the record for the entire growing season.

Table IV.—*Relation of Altitude to Evaporation from Free Water in a Corn Field, Nebraska Experiment Station, 1910.*

| Relation of Altitude to Evaporation in the Corn Field. | | Relation of Altitude to Wind Velocity in the Corn Field. | |
|---|---|---|---|
| Height Above Ground in Inches. | Total Grams Evaporated in Season. | Height Above Ground in Inches. | Miles Wind August 5 to September 9. |
| 0 | 268 | | |
| 2 | 298 | | |
| 4 | 337 | 3 | 1,755 |
| 6 | 398 | | |
| 8 | 429 | | |
| 10 | 456 | 10 | 6,528 |

We see that the jars 10 feet above the ground lost almost twice as much water as the cans at the surface. Also the miles of wind at 3 feet above the ground and 10 feet above the ground were determined for the same period, and it was found that there was 3.8 times as much wind at the higher point as at the lower (3:10::1,755:6,528 = 1:3.8). It is apparent, therefore, that having the evaporimeters 3 feet above the ground as compared with having them level with the surface of the ground might make a difference of 25 or 30 percent in the amount of water lost during the season. The relative humidity in the air, also, is a very important factor on the amount of water loss. Table V shows data secured in two greenhouses, one of which it was attempted to keep at a much higher degree of humidity than the other. The dry greenhouse was simply left open so that it had the same humidity as the natural air. In the humid greenhouse the benches and floor were kept constantly wet and a set of atomizers was attached to the water system to increase the humidity as much as possible.

TABLE V.—*Relation of Water Used by Corn Plants to Humidity, Nebraska Experiment Station, 1911.*

| | Dry Greenhouse. | Humid Greenhouse. | Ratio, Humid to Dry. |
|---|---|---|---|
| Mean temperature 12 hrs. of night (F.) | 80° | 75° | |
| Mean temperature 12 hrs. of day (F.) | 91° | 88° | |
| Mean relative humidity 12 hrs. night | 48 | 72 | |
| Mean relative humidity 12 hrs. day | 37 | 58 | |
| Total weight of 8 plants in grams | 670.36 | 861.77 | |
| Average leaf area per plant in sq. in. | 1,079 | 1,070 | |
| Total water used (kilos.) | 227,785 | 184,230 | |
| Grams water to gram dry weight | 340 | 191 | 1:56 |
| Grams water per sq. in. leaf area | 27.3 | 19.2 | 1:70 |
| Water evaporated from 36 sq. in. free water surface (grams) | 3,891 | 2,187 | 1:56 |

The plants in both cases grew very normally, and we see that about twice as much water is required to give a unit of dry weight in the dry greenhouse as in the humid. A record was kept at the same time of the amount of water evaporated from a free water surface in the two greenhouses, and there was practically the same relation in evaporation from free water surface in both houses as in water loss from the crop.

The amount of water contained in the soil will also have a slight effect on the ratio. Table VI shows data secured at the Nebraska Experiment Station in 1910.

TABLE VI.—*Relation of Soil-Water Content to Plant Growth.*

| Saturation Maintained, Percent. | Total Water Transpired, Kilos. | Total Dry Weight of Plant, Grams. | Leaf Area, Sq. In. | Water Used per Gram Dry Wt., Grams. | Water Used per Sq. In., Leaf Area, Grams. | Leaf Area per Gr. Dry Weight, Sq. In. | Height of Stalk, Inches. |
|---|---|---|---|---|---|---|---|
| 100 | 108 | 373 | 1,109 | 290 | 97 | 2.97 | 100 |
| 80 | 127 | 484 | 1,313 | 262 | 97 | 2.71 | 101 |
| 60 | 106 | 442 | 1,206 | 239 | 88 | 2.73 | 92 |
| 45 | 68 | 297 | 1,211 | 229 | 56 | 4.07 | 75 |
| 35 | 28 | 111 | 853 | 252 | 33 | 7.65 | 51 |

The plants grown in the saturation of only 35 percent did not grow normally, as this percent of moisture was too low for proper growth, but in the other four cases the water requirement slightly increases as the saturation increases. The fertility of the soil used also has an effect on the water requirement. Table VII is a summary of data secured with three different types of soil, both manured and unmanured.

TABLE VII.—*Relation of Water Requirements to Fertility of Soil, Nebraska Experiment Station, 1911.*

| Crop. | Character of Soil. | Water Required per Gram Dry Weight. | | |
|---|---|---|---|---|
| | | Unmanured. | Manured. | Ratio. |
| Corn . | Very poor (15 bu.) . . . . . . . . . . . . . . . . | 549 | 350 | 1:63 |
| | Intermediate (30 bu.) . . . . . . . . . . . . . . | 478 | 341 | 1:71 |
| | Quite fertile (50 bu.) . . . . . . . . . . . . . . | 391 | 346 | 1:88 |

We see that the water ratio was very much decreased by manuring the poor soil but only slightly by manuring the more fertile soil. The size of jar used also has a marked effect. Table VIII is a summary of data secured by Leather at Pusa, India. He used four different sizes of jar, holding approximately 25, 50, 75 and 100 pounds of soil each.

TABLE VIII.—*Effect of Fertilizers or Manure on Water Requirements, as Reported by Leather, Pusa, India. Average of Seven Crops.*

| Small Jars. | | Large Jars. | | Field Plats. | |
|---|---|---|---|---|---|
| No Fertilizer. | Complete Fertilizer. | No Fertilizer. | Complete Fertilizer. | No Manure. | Manure. |
| 894 | 667 | 732 | 516 | 457 | 495 |

We find that the larger jars had a much smaller water requirement than the small jars, and when data were taken under field conditions with the same soils the water requirement was only about half as much as in the small jars. Also we find that the addition of manure to the soils in the jars decreased the water requirement while it did not have the same effect when added to field plats. The last three tables illustrate a principle which may be briefly summarized in the following statement—that *the more normal the conditions of water or fertility, the less the water requirement of the plant.* Where the water is excessive or deficient, usually the requirement per gram of dry weight is greater than where water is about optimum. As a general rule the lowest water requirement is secured at about 60 percent saturation (saturation here meaning the amount of water retained by the soil against gravity). We also see that when the soil lacks fertility the water requirement is very much higher than when in a fertile condition. This probably explains why in pot experiments the addition of fertilizers or manure has usually decreased the water requirement of the crop, and the smaller the pot used, the more striking the result; or, the more sterile the soil, the more striking the result. It is also interesting that where data have been taken under field conditions by Leather and King, they were not able to secure a marked result from the addition of manure or increasing of the available fertility. We may therefore conclude that when the fertility is below normal the addition of available fertilizer will decrease the water requirement, but for soil in a sufficiently fertile condition it probably will have no marked effect. Even when a fertile soil is used in a jar, the addition of fertilizer will probably decrease water requirement, since a small amount of fertile soil in a jar may furnish only a small amount of available fertility to the plant as compared with the large quantity of soil which would be available for the use of the plant under field conditions.

### *Relation of Water Requirement to Type of Plant.*

In a study which is to be taken up of the relation of water requirements to plants, it may be of interest to call attention here to the fact that the type of plant may be an important factor to consider. At the Nebraska Experiment Station for several years we selected two types of corn—one with broad leaves and one with narrow leaves. Data regarding these two types are given in Table IX.

TABLE IX.—*Relation of Water Requirements to Type of Plant. Nebraska Experiment Station.*

| | Average for 3 Yrs , 1907–'09–'10. | |
|---|---|---|
| | Narrow Leaf Selections. | Broad Leaf Selections. |
| Leaf area per plant (sq. in.) | 1,017.0 | 1,385.0 |
| Water used per plant (pounds) | 239.0 | 303.0 |
| Average weight ear (grams) | 245.5 | 277.5 |
| Tons water to produce one bu. | 16.1 | 18.1 |
| Tons water to produce 50 bu. | 806.6 | 939.0 |

We find here that the water loss is very closely related to the leaf area—much more closely to the leaf area than to the dry weight; hence we may conclude that leafy types of plants require larger degrees of water. It is shown in this table also that the amount of water required to make a 50-bushel crop is about 130 tons greater in the one case than in the other.[6] We should expect the narrow leaf type, therefore, to be more drouth-resistant, or better able to withstand dry conditions. Data have been secured for four years under field conditions with these two types of corn. Three of these years have been dry years, especially during the period from tasseling to the maturity of the corn. One year, that of 1910, was a season of heavy rainfall, there being that year 14 inches of rain during the month of August. During the three dry years, corn from the type having the narrow leaves has given much the best yield. During the one year of heavy rainfall the leafy type gave best results. It may be inferred from this that under conditions of deficient rainfall and excessive sunshine, narrow-leaved types of plants will be found best, and under conditions of large rainfall and perhaps deficient sunshine the broad-leaved type will give best results.

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[6] Montgomery, E. G. 24th Ann. Rept. Nebr. Exp. Sta., 1911, p. 155.

### *Relation of Water Loss to Climatic Factors.*

In our experiments it was often noted that the water loss from day to day showed a great variation. Table X shows the variation in water loss from an average of twelve plants during one week; also the corresponding amount of water evaporated from free water surface.

TABLE X.—*Daily Variation in Transpiration. Average of 12 Corn Plants. Nebraska Exp. Sta., 1910.*

| Interval of 24 Hours Ending 7 P. M | Water Transpired per Plant (Av. 12 Plants), Grams. | Water Evaporated from Free Water Surface (Av. 6 Jars), Grams. |
|---|---|---|
| July 27, 1910 | 4,550 | 454 |
| July 28 | 2,333 | 372 |
| July 29 | 1,579 | 173 |
| July 30 | 2,802 | 232 |
| July 31 | 3,561 | 314 |
| Aug. 1 | 3,982 | 374 |
| Aug. 2 | 3,419 | 311 |
| Aug. 3 | 2,143 | 204 |

On some days three times as much water was required as on others, and about the same variation was shown in the evaporation from a free water surface. Fig. 49 shows the daily variation in water loss from the plants as well as variation in water lost from a free water surface for a period of 30 days, from July 20 to August 20. We see here a very close correlation between water lost from a free water surface and that lost from the plants.

This same principle is illustrated in a more marked way by Fig. 50, which gives the average water loss together with evaporation and certain weather factors plotted by the hour for the 24 hours of day.[7]

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[7] Montgomery and Kiesselbach. 24th Ann. Rept. Nebraska Exp. Sta., p. 100, 1910.

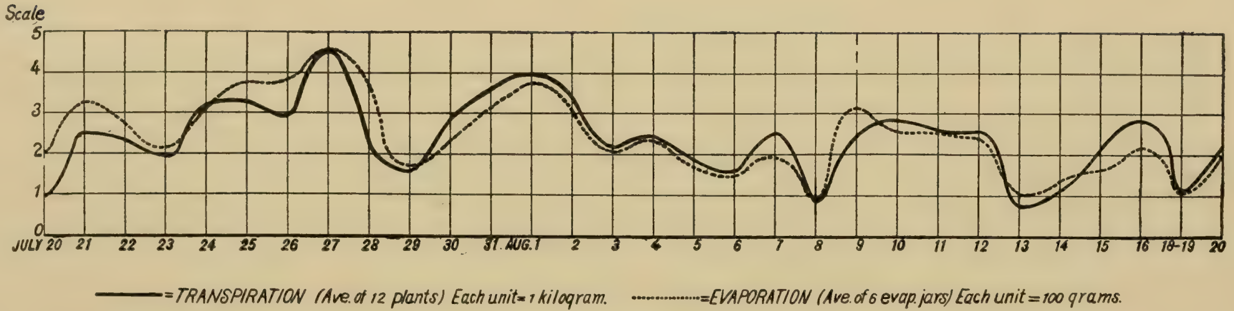

FIG. 49.—The daily transpiration and evaporation data of Table X, plotted to show the close relationship between transpiration by plants and the evaporation from a free-water surface. (Courtesy Nebr. Exp. Station.)

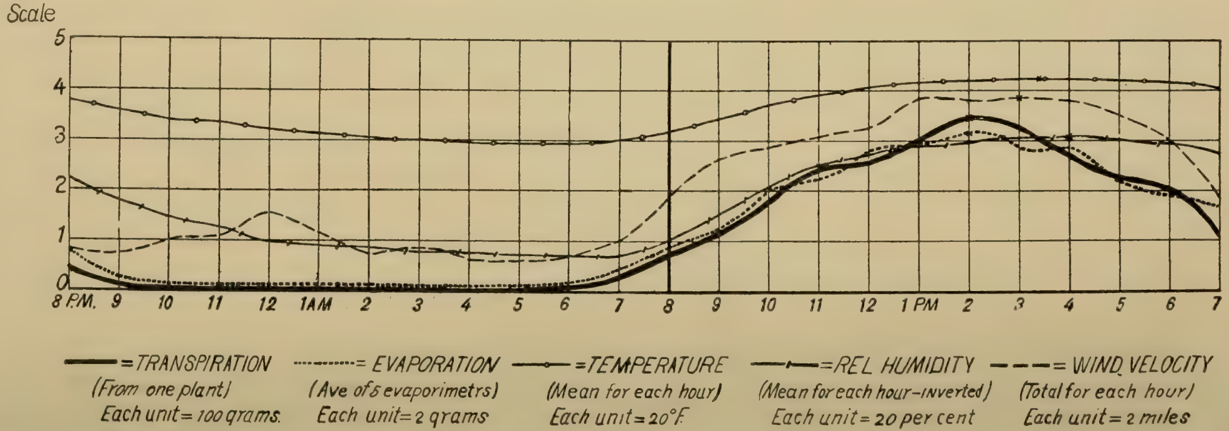

FIG. 50.—Summary of the transpiration, free-water surface evaporation, and weather factors, during successive hours of the day and night. (Courtesy Nebr. Exp. Station.)

These figures are the result of hourly weighings for a period of two weeks. We find that during the night the water loss from the plants is very low, but it begins to increase about 7:00 o'clock in the morning, reaching the maximum loss per hour at 2:00 o'clock and again declines till about 8:00 in the evening. It is remarkable that the evaporation from a free water surface varies in exactly the same way and in practically the same degree. It might be expected that during the heat of the day, when maximum evaporation was taking place, the plants would exercise some physiological control of their water and tend to lag behind evaporation from a free water surface. It also would be expected that during the night, when evaporation from a free water surface was very low, the plants would tend to increase their loss in proportion to that from a free water surface. The correlation, however, between the two is very close. It is also noticeable that the curves for humidity, temperature, and wind velocity reached their maximum at 2:00 o'clock in the afternoon or at practically the same point where evaporation and transpiration are at maximum. This would indicate that plants respond to climatic conditions in ex-

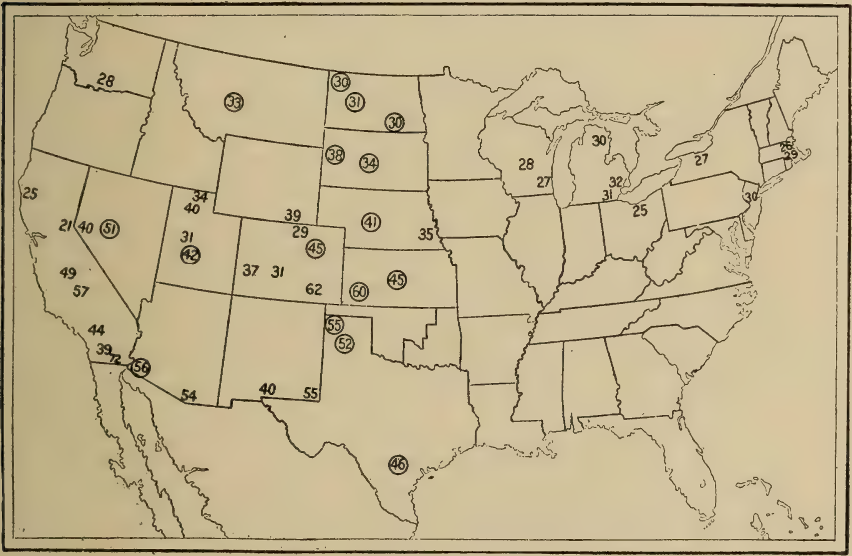

FIG. 51.—Chart showing the evaporation in inches during the six summer months from April to September, inclusive, for various points in the United States. The circles show stations where evaporation measurements are being made in connection with the field experiments of the Bureau of Plant Industry. The evaporation at these stations is measured in the same way and can be directly compared. (From U. S. Dept. Agric., Bur. Plant Industry, Bul. 188.)

actly the same way that a free water surface responds, and apparently exercise little or no physiological control of their water at periods of greatest water requirement. We should therefore expect that if accurate data were secured on the different climatic conditions as to the amount of water evaporated from a free water surface during the growing period, it would give a good indication of the amount of water required by crops. The water required for different seasons also varies. For example, in 1910 the average ratio secured in one set of 12 plants was 250, while in 1911 under very similar conditions, in the same cans and location, the ratio was 345 or 38 percent more.

Fig. 51 is a chart prepared by Briggs and Belz,[8] showing the evaporation records for the growing season which have so far been secured. Not all these records have been secured by the same method and so are not strictly comparable, but they would indicate that it probably takes twice the amount of water to produce a crop under Texas conditions than would be required in the state of Washington. Before such general conclusion can be drawn, however, careful comparative experiments should be made under a great variety of conditions, determining the water requirements of plants in connection with the evaporation from free water surface.

### *Suggestions Regarding Method to be Used.*

In the foregoing I have attempted to point out very briefly some of the factors which affect water loss, and it is evident that the difference in exposure to wind, the difference in the height above ground where data are taken, the fertility of the soil used, and various other factors will greatly modify results. It would be of much greater value to the scientific world if some standard method of securing such results would be adopted by the various investigators, so that a comparison could be made between one region and another. The can used should be large enough to give approximately the same area to the plants both in depth and in surface that they have under average field conditions. The fertility of soil should be at least normal. The water supply should be kept at about optimum. Cans should be used from which all evaporation can be prevented and all intake of water from rains, so that the cans can be left in the field during the entire growing season under actual field conditions. It would be desirable, in each case, to use different types of soil, both manured and unmanured. Water loss from a free water surface should be determined at the same time from a standard tank, preferably the one now adopted by Briggs and Shantz in their determinations. Also automatic hygrometers, thermometers and wind gauges should be kept in operation during the growing season, so that a complete set of data in each case can be secured.

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[8] Briggs, Lyman J. and Belz, J. O. U. S. Dept. Agr., Bureau Plant Industry, Bul. 188, 1910.

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